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Cross Road. .....

Cart Track. .....

Flat Shade of Green

Footpath. .....

Railroad .....

.....ditto..... Single Line

Canal. .....

: without trees.

Electric Telegraph.

The horizontal line is only ne
follow a

Rive

Inches to 1 mile.

Ford

Ferry

pr Chapel. .....

l. .....

l. .....

1 Bridge of Iron..... I.

..... „ ..... Wood..... W.

..... „ ..... Stone..... S.

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AND

FIELD SKETCHING.

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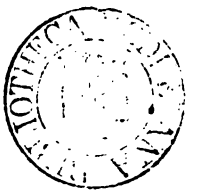
SCALE OF SHADE,
EXAMPLES IN MILITARY DRAWING,

ETC. ETC. ETC.



BY

MAJOR W. H. RICHARDS,

Fifty-fifth Regiment.

LATE INSTRUCTOR OF MILITARY SURVEYING, ROYAL MILITARY COLLEGE, SANDHURST.

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PREFACE.

It has been the endeavour of the Author, in writing the following pages, to state in the simplest manner the operations of Military Surveying and Field Sketching, to exclude as far as possible unnecessary calculations and all matter not strictly practical, and to arrange the different parts of the subject in the natural sequence in which a beginner would best acquire them. He has been induced to undertake this in consequence of the want frequently expressed by beginners, of a simple and practical work from which they might learn military surveying as it is at present taught, and he trusts that some years' experience in teaching may qualify him to meet the requirement.

The method that has been adopted within the last few years of sketching ground by contours, and expressing slopes according to a Scale of Shade, has necessitated some explanation of matter not treated of in most of the earlier works on the subject.

The Section on Military Landscape Drawing, and on the study of Geology in connection with Surveying, is by Captain Fothergill, F.G.S., Instructor of Surveying, Royal Military College.

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XVIII.—Examples in Military Drawing

XIX.— „ „

XX.— „ „

XXI.— „ „

THE following portions are inapplicable to the course of Garrison Instruction:

Section III. as far as page 19.

Sections VI., VII., VIII., and IX.

From Page 65 "TRAVERSING" to Page 69 "PLOTTING."

Sections XIII. and XIV.

From Section XIX. to the end of the book.

ERRATA.

Page 2, line 12—For "place" read "plan."

Page 17, line 19—For "at which," read "*to* which."

Page 24, 12th line from bottom of page—After "C,D,E,F,G,H,K," insert "Plate II."

Page 30, line 5—After "as shown" insert "Fig. 21."

Page 30.—Fig. 22 should not be placed in the page, but under the note which it illustrates at the foot of the page.

Page 49, line 5—For "Sextant and," read "Sextant *to*."

Page 58, line 12—For "Page 43" read "Page 53."

Page 95, 5th line from bottom of page—After "in this form" insert "Fig. 52."

Page 109—Omit para. commencing "A process" and ending "point F."

Plate V.—The circular protractor B should be shown graduated 180°, 190°, 200°, &c., instead of 180°, 200°, 210°, &c.

Plate VII.—The meridian should be shown parallel to a,b.

The centre of the protractor should be marked "C" instead of "U."

Plate XI., Fig. 1—c,b should be marked 18.75, instead of 18.5.

Plate XIII.—Not accurately drawn to scale.

Fig. 65—Not quite accurate.

MILITARY SURVEYING AND FIELD SKETCHING.

SECTION I.

INTRODUCTORY REMARKS.—SCALES.

SURVEYING is the art of ascertaining by measurement the shape and size of any portion of the earth's surface, and representing the same on a reduced scale in a conventional manner so as to bring the whole under the eye at once.

In military surveying the attention is chiefly directed to representing those objects which are of tactical importance, such as hills, showing their steepness, their relative height and the form of each feature; roads, and all lines of communication; rivers, showing fords, &c.; marshes, woods, fences, and all other objects which might affect the movements of the various arms.

The principal conventional signs used in military surveying are shown in Plate I.

When accuracy is of more importance than time, and good instruments can be employed in the measurements, these being laid down at leisure, with minute finish, it is called a Survey or Plan.

A military sketch is supposed to be undertaken under conditions in which time is limited and extreme accuracy is not expected, and it is such as could be performed entirely in the field and with the simplest instruments.

The combination of rapidity and accuracy necessary in good field sketching can only be obtained by practice in the application of the principles of regular surveying, which must be mastered in the first place by the beginner.

SCALES.

The first point to be considered is the scale on which the plan is to be drawn, *i.e.*, the proportion which it is to bear to the ground represented.

If a plan were to represent an object at half its actual size we should say that the *representative fraction* of that scale was $\frac{1}{2}$.

In the same way, if a line, the actual length of which is a mile, be represented in a place by a line a yard long, the representative fraction would be $\frac{1}{1760}$, and if a foot long $\frac{1}{5280}$.

But in military plans it is customary to adopt a scale representing a *mile* by a certain number of *inches*, thus in speaking of a plan as being on the scale of 8 inches to a mile, that expression seems to convey a more tangible idea of its proportion than the equivalent mathematical expression $\frac{1}{7920}$. The representative fraction should, however, be also stated on the plan or sketch, as the mile and inch being arbitrary measures applicable to English operations only, will convey no idea of the relative proportions between English and Foreign plans in which the same standards of measure are not used.

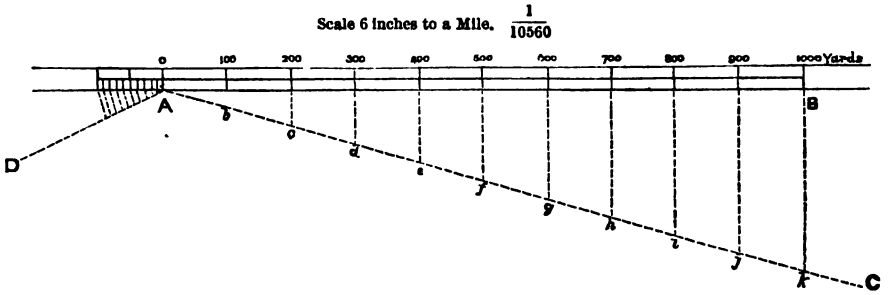
The scale we should choose at which to execute a plan will depend on the nature of the ground and the amount of detail required. For towns, from 30 to 120 inches to a mile is generally used; for sketches of military positions, from 6 to

12 inches to a mile; for a line of road, from 1 to 6 inches to a mile.

To construct a scale of 6 inches to a mile to read yards.

Since 1760 yards are represented by 6 inches, 1000 yards will be represented by $\frac{6 \times 1000}{1760} = 3{\cdot}4$ inches. Take a line A B 3·4 inches long and divide it into 10 equal parts, each of which will be 100 yards.

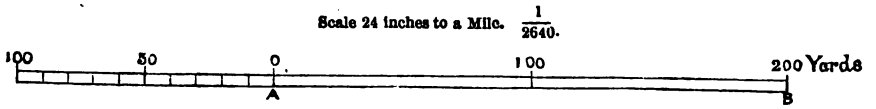
Fig. 1.



This may be done by drawing another line A C at any angle with A B, on this lay off 10 equal parts *b*, *c*, *d*, *e*, &c. Join B *k* and draw parallels to this from the points *j*, *i*, &c., intersecting A B in the required ten equal parts. Produce A B to the left 100 yards and divide this in the same manner into ten parts each equal to 10 yards.

In constructing a large scale (say 24 inches to a mile) 1000 yards would be of an inconvenient length, take any smaller number of hundreds 200, then $\frac{24 \times 200}{1760} = 2{\cdot}72$ inches will be the length of the scale A B, which will be divided into 2 equal parts.

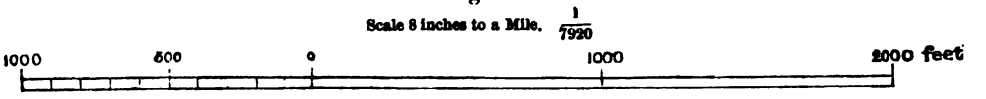
Fig. 2.



To construct a scale of 8 inches to a mile to read feet,

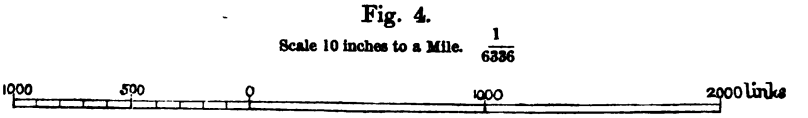
in this case we cannot conveniently show such small quantities as 10 feet, we should therefore divide the scale into thousands and hundreds of feet. Since 8 inches represents $1760 \times 3 = 5280$ feet, 2000 feet will be represented by $\frac{8 \times 2000}{5280} = 3{\cdot}03$ inches, and will be divided thus:

Fig. 3.



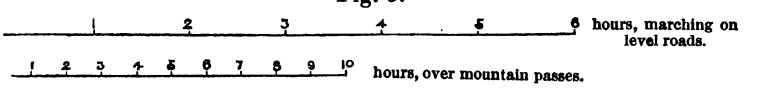
To construct a scale of chains 10 inches to a mile—in scales of chains the link is usually taken as the unit of measure. Then, since a mile, 8000 links, is represented by 10 inches, a convenient length, 4000 links, will be 5 inches long, divided thus:

Fig. 4.



It must be remembered that in military operations *distances are to be measured by the time taken in traversing them,* and in mountain districts, where the time occupied in marching, distances will vary greatly with the nature of the ground, a scale of time, framed on our experience, will be a most useful addition to a plan or map.

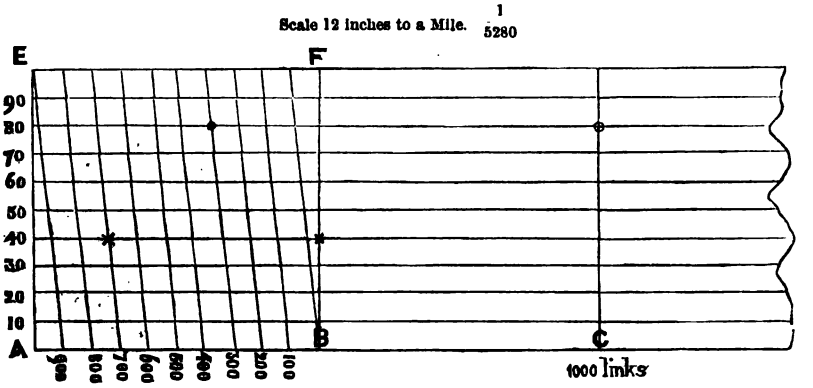
Fig. 5.



In regular surveys, when the measurements are made with the chain, the scale is generally constructed on the diagonal principle, so as to measure minute quantities, thus:

Supposing the required scale to be 12 inches to a mile, a convenient length, 3000 links, will be $\frac{12 \times 3000}{8000} = 4{\cdot}5$ inches long. Take A D = 4·5 inches and divide it into 3 parts of 1000 links each, B and C.

Fig. 6.



Draw 10 lines parallel to A D at any convenient equidistance and raise perpendiculars to A D at A, B, C, D. Subdivide the left division A B and E F into 10 parts of 100 links, join these points of division diagonally and number the scale as shown; then, if a distance of, say, 740 links is to be taken, we place the points of the compasses at x, x; for 1380 links at o, o.*

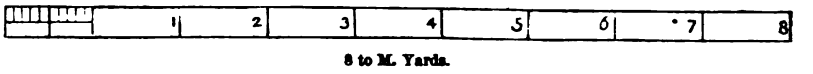
As, in sketching, the measurements are made by pacing in yards one or two convenient scales, usually 6 and 8 inches to

* We may employ the Marquois scales with advantage in the construction of these scales of *links*, thus: supposing the scale required to be 12 inches to a mile, we find that the outer or artificial edge of the Marquois scale 20 is 12 inches long, and divided into 8 principal and 80 minor parts, as required for the construction of that scale of links, and we have only to hold it firmly on the plan in an upright position and dot off from it the required parts. In the same way the Marquois scale 30 is suitable for the construction of a scale of 8 inches to a mile, 40 for 6 inches to a mile, and 60 for 4 inches to a mile.

The reader will see what is meant if he applies the Marquois scale 20 to the scale given above.

a mile, are engraved on the ivory protractor, the smaller divisions being tens, the larger hundreds of yards, thus:

Fig. 7.



If sketching on a scale which is not engraved on the protractor, we may still use the scales for any of their multiples or measures. From the scale of 6 inches to a mile we may take 3, 12, 18, &c., from that of inches 8 to a mile, 4, 16, 24, &c.

For example, a wall 300 yards long would be represented in a plan of 8 inches to a mile as of a certain length.

If the plan were 16 inches to a mile it would be represented as double that length, or the same thing as 600 yards on the scale of 8 inches to a mile.

The method of applying the scale in the field for sketching on a scale which is a multiple of one of those given on the protractor then is—Multiply the actual dimension by the required increase of the scale, and take it from the scale as it stands.

All chance of error on this account may be easily avoided by constructing the required scale on the edge of a stout card; and the beginner will probably find that by using this instead of the scale on the protractor, he will save time and trouble.

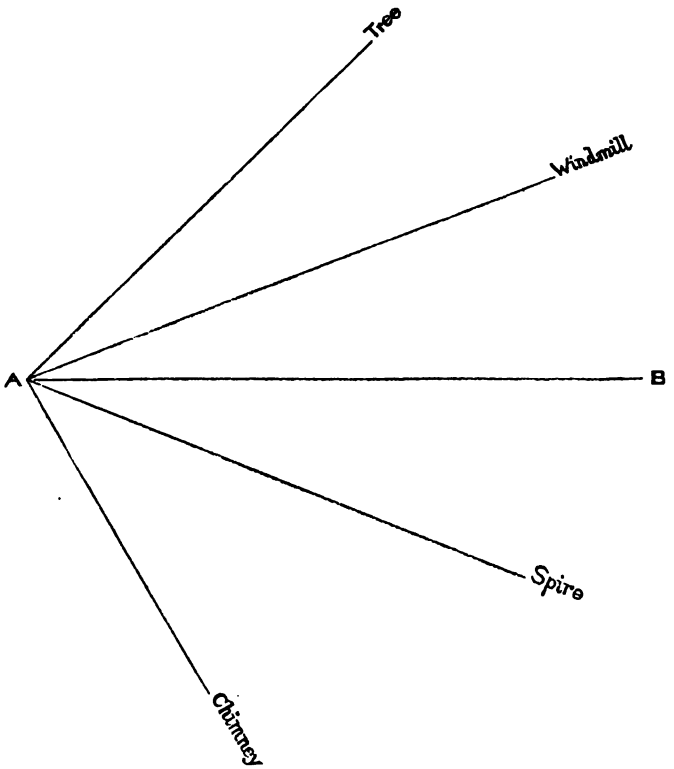
Measurements in the field should be always taken direct from the scale by applying it to the plan; compasses should not be used for the purpose.

SECTION II.

BASE AND TRIANGULATION.

In all surveys and sketches of positions of any extent, where accuracy is desired, the first step, before proceeding to

Fig. 8.

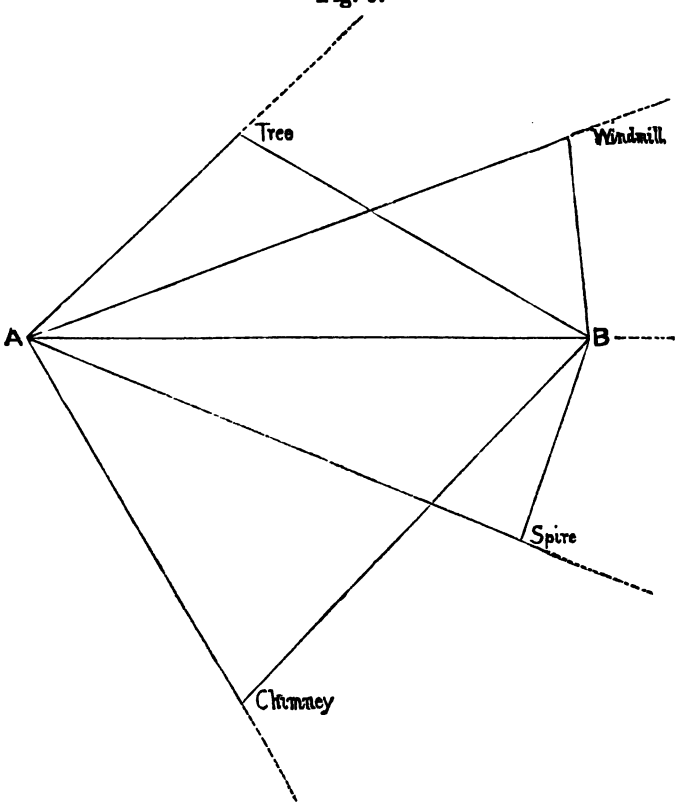


the survey of the details of the ground, must be to ascertain and lay down on the plan with precision the relative positions

of a few conspicuous objects throughout the extent of the ground. This is performed by Triangulation, in describing which here, no mention will at first be made of any instrument, for the sake of placing the problem in its simplest form.

If we stand at a commanding point of view, whence we can observe the direction of objects in the surrounding country, and, taking a sheet of paper, make a point A upon it, to represent that at which we are standing, we can from this point upon the paper draw lines towards the objects we have chosen.

Fig. 9.



Suppose, now, we measure the distance in a straight line to any one of them, B, and having laid down the length to any required scale, take our paper there, and placing it so that the

line B A is directed on A, draw lines to the same objects, the intersection of the relative lines from the points A and B will fix the position of all the others, and the points thus found on our paper will have a similar position to that of the objects in the surrounding country. These points are termed *Stations*, or when found by calculation, Trigonometrical points.

It must be observed that the slightest inaccuracy in the direction of lines intersecting either in a very acute or obtuse angle (*a* and *b*) will greatly alter the position of the point of intersection, and that the same amount of inaccuracy will displace the point least when the lines intersect at a right angle (*c*).

Fig. 10.

In order to insure accuracy in the position of Stations therefore, we must consider the necessity of obtaining good intersections, and if the Stations thus fixed by well proportioned triangles constructed on the original base, do not extend over the whole tract of country to be surveyed, we may construct other triangles upon these (the sides of each triangle furnishing bases for fresh ones) and build triangle on triangle until the network covers the required space.

Fig. 11.

These stations provide us with starting points from which to commence the survey of the details of the ground, to check the correctness of the work as it proceeds, and to facilitate its progress generally.

The measurement of the original base is the most important

part of the survey, as upon its accuracy depends that of every subsequent part of the work.*

The length of the base (and consequent size of the triangle) must be proportioned to the extent of country to be surveyed, but as a general rule, it must be as long as possible consistent with the circumstances under which the work is performed, the length of the Base for a survey of 50 square miles would be from 1 to 3 miles; for 10 square miles, $\frac{3}{4}$ to 2 miles; 1 square mile, 600 to 1200 yards. If shorter bases be used, the number of well proportioned triangles to cover the ground would be greater, and the chance of error would be increased consequent on the necessity of a greater number of observations.

The ground on which the base is measured should be tolerably level, in order to avoid the calculations necessary in hilly ground for the reduction of the measurements to their true horizontal length; gentle slopes, however, up to about 4° or 5° have a comparatively slight effect on linear measurements, and if the ends of the base line are otherwise well situated (*i.e.*, so as to command an unobscured view of the surrounding country) the existence of such undulations in the intervening ground need not be considered a great drawback, since, in the limited extent of country which an officer's sketch will usually comprise, there will rarely be found a perfect position for a base.

The base should be laid as near the centre of the proposed

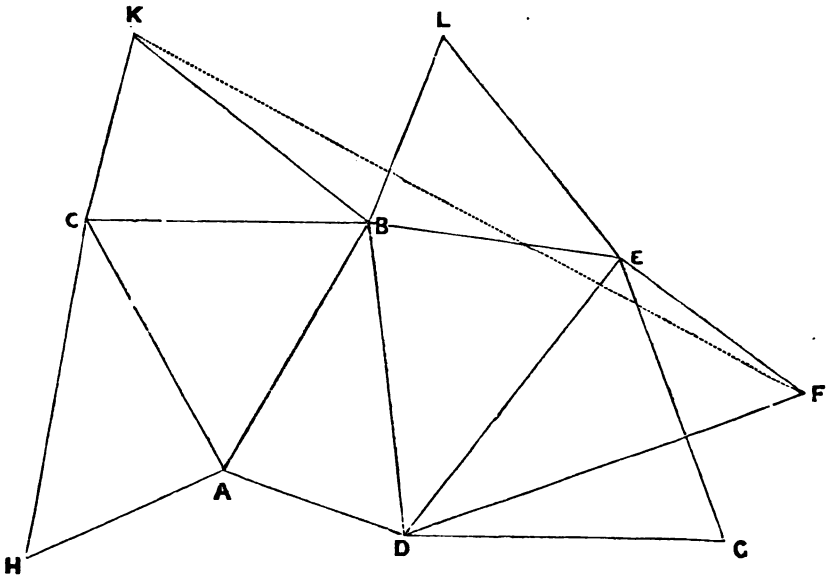
* In extensive National surveys this operation is performed with great labour and cost, with a variety of measuring instruments least susceptible to atmospheric influence, such as rods of glass and deal, steel chains and compensating bars, consisting of bars of different metals so joined together that the variations of temperature acting upon them in different known proportions, they may, by their construction, preserve minute marks at their extremities, at the same distance from each other, under all atmospheric conditions. It would be out of place here to enter into any details of operations of this important nature—a perusal of the subject in any work on Geodesical Surveying will be found interesting.

survey as convenient, since the liability to inaccuracy in the triangulation increases with the distance from the original base.

It has been remarked that in selecting stations we must be influenced by the consideration of the necessity of securing a good intersection at each: if the triangulation is, however, to be carried out to any extent, we must be careful that, in following out this idea, we do not on the other hand reduce the size of the triangles.

The best form of triangle is the Equilateral, as the intersection at an angle of 60° is sufficient to determine the Station with accuracy, and without a loss of length of base for the subsequent triangles.

Fig. 12.



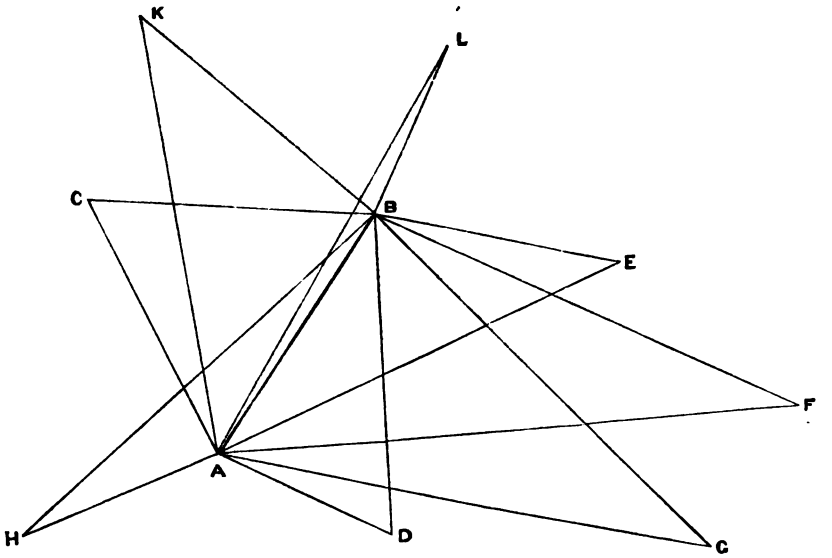
The rule in choosing Stations therefore is, that they should not be at a much greater distance from the ends of their base than the length of that base, and that they should not lie much behind either end of it.

The accompanying Figures are shown as an illustration of these principles, being a badly and a well arranged triangulation of the same Stations.

In 13 the common error of intersecting a great number of Stations from the ends of the original base has produced several badly formed triangles, the intersections at H, K, L, F & G, being too acute.

In 12 the Stations C and D only were intersected from the original base, the other points being determined by successive triangles of good form constructed on these.

Fig. 13.



We may occasionally verify the accuracy of the triangulation by observing the direction of a Station from two or three other Stations, and if these lines converge on the same point it is a satisfactory proof not only of its accuracy, but of that of each of the Stations whence these observations are made. When good instruments are used, and proper care taken, this test need only be occasionally applied. For instance, if an

observation from F be found to pass through K (I), it is a sufficient proof of the accuracy of the whole series of triangles on each side of the original base from which these two points are derived. This is termed the *Angular test.*

The *Linear test* or measurement of a "base of verification" consists in measuring on the ground a side of a triangle, or distance between two Stations remote from the original base, and comparing this measurement with the corresponding calculated length, this test is applied in important surveys where the length of the sides of the triangles is calculated trigonometrically.

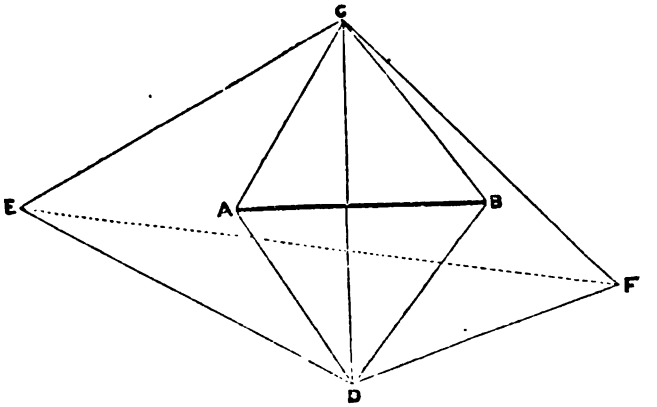
It is a common error to suppose that the value of a triangulation is increased by having a great number of Stations; the principal Stations should, on the contrary, be few and equally distributed, the crowding of triangles merely causes confusion where simplicity is of importance. Should it subsequently be found necessary to determine any Station, it is done by secondary triangles formed within the principal ones.

For sketching purposes, it is unnecessary to have stations nearer than 2 or 3 inches from each other on paper, so that when working on 24 inches to a mile we should have them 200 or 300 yards only apart on the ground, whilst if sketching at the scale of 4 inches to a mile, we should select suitable points about $\frac{1}{2}$ a mile apart.

When we are unable to obtain a base of sufficient length (as, for instance, in a hilly piece of ground where it has to be taken along a valley) it is important that the size of the triangles be gradually increased, so as to obtain a greater length of base for the succeeding triangles, but in such a manner as to avoid the introduction of badly formed triangles. This may be performed in the manner shown in the accompanying figure. Suppose A B to be the original base, the Stations C and D may be determined therefrom; take C D as a fresh base of increased length, whence we may intersect E

and F, and regard the line E F as another base, and so continue to increase the size of the triangles until the length of their sides is limited by the telescopic power of the instrument, or by the range of the human eye.*

Fig. 14.



In setting up marks for Stations, such as flags, &c., it must be borne in mind what appearance they will present from the point of observation. On high ground, where the Station will have a background of sky, a black object will be the most distinct, but in low ground, or where the background will be dark, a white object will show the best contrast.

When the Theodolite is used for observations, the ends of the base, as well as all other Stations at which it will be used, should be marked by a flag or pole, which can be removed to allow of the instrument being placed exactly over the Station.

* In extensive surveys, distant observations are frequently made on clear nights, the locality of the Station being shown by a powerful light, such as the lime light, by means of which Stations have been made discernible in the hazy atmosphere of Great Britain at upwards of 70 miles distance.

The Heliotrope, an instrument for concentrating and reflecting the rays of the sun in a given direction, is also used; by its assistance a very distant Station appears in daylight like a brilliant star, when much nearer objects are quite invisible through the obscurity of the atmosphere.

It is comparatively easy to lay out a triangulation with judgment in a hilly country: but in a wooded flat country much difficulty will often be encountered in securing the visibility of Stations from the points of observation. The marks set up as Stations should be as high as possible, in order that they may not be obscured by hedges, underwood, &c.; in wooded country the best mark is generally a tall pole, with a disc or cross (black or white according to background) fastened in the top of a high tree, so as to stand above it; the Stations intended for points of observation must, however, be kept in open ground.*

If a tree be chosen as a Station it will be seldom so remarkable as to secure its recognition from all directions, and we should fasten a flag or other mark in it. A piece of white paper fastened to a tree will generally last during the time required to execute a military sketch. In small sketches, however, trees may sometimes be found sufficiently conspicuous to answer the purpose.

In military sketches we overlook the corrections which are necessary in extensive works for the reduction of the sides of the triangles, on account of the spherical form of the earth; we regard the earth as a plane and the sides of the triangles as right lines.

* In the plains of India it was found necessary to erect towers from 30 to 150 feet high for observatories, in order to clear the vegetation and the sphericity of the earth.

SECTION III.

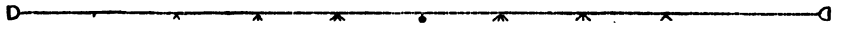
MEASURING.—PACING.

The chain is 22 yards long, including the handle at each end, and is formed of 100 long links joined by smaller rings, the length of the link being measured from centre to centre of these rings. The reason for adopting this length is its convenience in both linear and superficial measurements, as a mile contains 80 chains (8000 links), and an acre 10 square chains.

It is usual to describe all linear measurements as so many *links* when the chain is used.

At each 10 links in the chain, from both ends to the centre, there is a brass label with one, two, three, and four tongues; the centre or 50 links is denoted by a round label, this enables the surveyor to count at a glance the number of links measured, without the necessity of counting them from either end of the chain.

Fig. 15.



The chain is used by two persons, the leader and the follower. The leader is provided with 10 iron arrows, and walks in the required direction until nearly at the chain's length from the starting point, when the follower halts him, and dresses him in the proper direction by beckoning him to the right or left, allows him to draw the chain a foot or so beyond the starting point, and then pulls the chain steadily

back until the outside of the handle touches the starting point, the chain being kept at fair tension, but without jerking or hauling. The leader then sticks an arrow in the ground, touching the inside of the handle at his end, making also a score on the ground in case of its being accidentally displaced, to avoid the occurrence of which, the leader should give the chain a cast to one side each time he starts afresh, so that it may run forward clear of the arrow. The leader having placed his arrow, calls "all right," when they start again, the follower taking up each arrow when the leader has marked his end of the chain, *and not till then*, else they will risk losing their place.

When the leader has expended his 10 arrows, 1000 links is noted in the Field Book; he then measures out another chain and places his foot on the handle, and waiting till the follower comes up and returns him the arrows which he has picked up, he counts them to see that none is missing, *plants one at the spot*,* and they start afresh. On arriving at the point at which the measurement is to be made, the leader passes it until the chain is adjusted by the follower, both then count the arrows in their hands to see that they have the ten between them; the entire length measured is thus reckoned; the number of times the 10 arrows have changed hands, as thousands of links; to which is added the number of arrows in the follower's possession (including that marking his end of the chain) as hundreds: and the odd number of links counted on the chain to the required point as tens and units.

All these details must be systematically carried out, and it is better that the chaining be performed by two persons only. Assistants often cause mistakes by mixing the leader's and follower's arrows.

It is evident that a measurement made on sloping ground

* It is at this stage that mistakes are most commonly made.

as A B must be reduced according to the amount of slope to bring it to its true horizontal length or projection, A C.

Fig. 16.

The following table gives the necessary reductions to be made from each 100 links measured, for different inclinations.

Degs.	Links.	Degs.	Links.	Degs.	Links.	Degs.	Links.
*5	00·4	14	03·0	23	07·9	32	15·2
6	00·6	15	03·4	24	08·6	33	16·1
7	00·7	16	03·9	25	09·4	34	17·1
8	01·0	17	04·4	26	10·1	35	18·1
9	01·2	18	04·9	27	10·9	36	19·1
10	01·5	19	05·4	28	11·7	37	20·1
11	01·8	20	06·0	29	12·5	38	21·2
12	02·2	21	06·6	30	13·4	39	22·3
13	02·6	22	07·3	31	14·3	40	23·4

It will be found in practice that (with the exception of the measurement of the base, where every means of securing accuracy should be adopted, or when the plan is on a very large scale) it will be unnecessary in military surveys to take these deductions into consideration at all, as they are usually quantities so small as to be inappreciable when drawn to scale on paper.

When time admits, the base should be measured two or three times and the mean adopted. When the chain is used the shortest measurement is generally the most correct.

As the chain is formed of a number of long links easily bent, and short unwelded rings liable to be expanded at the

* This table is formed by subtracting the natural cosines from radius.

joints, it is necessary that its length should be occasionally tested by a standard chain, and whilst using it we should observe that it has not a "kink" or knot in it, and that none of the links are bent.

PACING.

In sketching small portions of country, and in such work as an officer is called upon to perform in an emergency, he will of course be unprovided with a chain. He must then determine the length of the base by pacing.

The natural walking pace of different individuals varies, but most persons may train themselves into pacing yards with considerable accuracy. The regulation pace of 30 inches is well adapted for parade purposes, but if one walks in a free, swinging manner, one will find the pace usually more nearly 36 inches. When walking quickly, though we seem to ourselves to be only taking our steps rapidly, we really increase the length of the pace also.

The best practice is to pace a measured distance of two or three hundred yards, altering the length of the pace till the distance can be covered in that number of steps within three or four.

This power of correctly measuring distance by pacing is of the first importance to a military surveyor, and should be frequently tested.

A mounted officer should ascertain by experiment the length of his horse's paces at the walk, trot, and gallop. The walk will be found to be of quite as constant a length as that of a man. The average paces of a horse per minute are about

from 110 to 120	walking.
230 to 260	trotting.
450 to 500	galloping.

We may occasionally obtain a very true estimate of distance on a road, by multiplying the measured circumference of the wheel of any vehicle by the number of revolutions it performs in traversing it. The revolutions of a moderate sized wheel drawn by a horse at a trot, are easily counted when a white mark is attached to one of the spokes.

Distances may be roughly judged by the time taken in traversing them, whether on foot or horseback.

The time taken in the transmission of sound, may be converted into distance, as sound travels 1118 feet in a second.

It is said that windows of houses may be counted at 4000 yards, and that horses and men present different specific appearances at certain distances; but as these phenomena depend on variable circumstances, they cannot be considered sufficiently definite for surveying.

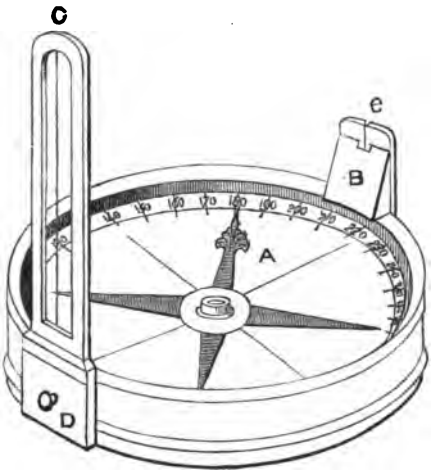
The military surveyor should endeavour from the commencement to educate his eye to the estimation of distances, not only of men or horses, but of all natural objects. This faculty, carefully cultivated, will go far towards enabling him to sketch rapidly and correctly.

SECTION IV.

THE PRISMATIC COMPASS.—OBSERVATION OF THE TRIANGULATION.

This instrument consists of a magnetic needle balanced on a pivot, and carrying a card A, or a metal ring divided into

Fig. 17.



360° and half degrees, this is contained in a box, at one side of which is a sight vane C; at the opposite a glass prism B, enclosed in a metal case, enables the divisions of the card to be read at the same time that the eye is close to the slit *e*, and is directed on the distant object.

Both the sight vane and prism may be turned down when not in use, and the whole shut in by a metal cover.

The Prismatic Compass gives us the *bearing* of a line, that is, the angle formed by the line with the magnetic meridian, called the *magnetic azimuth.*

To observe the bearing of an object. Turn up the prism and sight vane, hold the compass with both hands at some distance from the eye, watch the vibrations of the card, and by means of the knob D (which, when pressed, touches the edge of the card) check its swing if necessary. When quite settled, bring it up slowly to the eye, keeping it quite horizontal so that the card may not touch the glass cover, look through the slit *e*, and direct the hair of the sight vane C on the object, the bearing will then be seen on the card in coincidence with the hair. The graduation of the compass will be read from right to left like the hands of a watch.

We have no means of ascertaining smaller quantities than half degrees except by estimation. After a little practice, however, we may obtain bearings thus to within 15′ under ordinary circumstances.

When once the compass is at the eye the spring D should not be touched, as to obtain a correct bearing the card must of course be perfectly free; but it should be at rest by itself before bringing it to the eye, else the hand and eye will be fatigued while watching for the cessation of its vibrations.

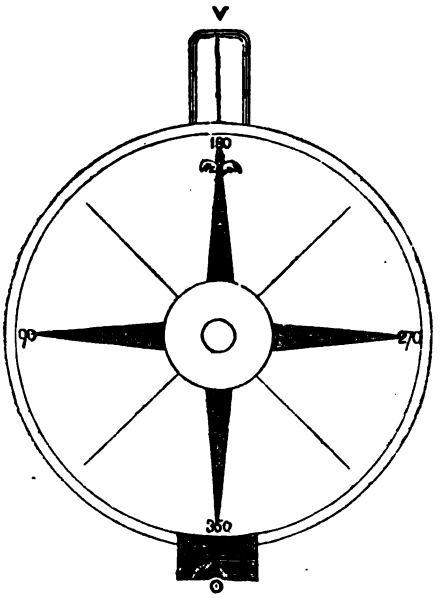
Sometimes the Prismatic Compass is screwed on a light tripod stand; but though at first sight this arrangement would seem advantageous as ensuring steadiness, yet it is questionable whether the slight motion of the hand is not of advantage in keeping the card *alive;* especially if the compass has been some time in use, and the point of the pivot has become somewhat blunted.

In windy weather it is necessary to sit or kneel, resting the elbow on the knee in order to obtain an accurate bearing.

It will be seen that in the card of the compass the order of the degrees is reversed, North is marked 180°, South 360°,

East 270°, and West 90°. This is done that the degree due to the magnetic direction of the observed object may appear under the prism, which of necessity is placed at the opposite side of the instrument to the direction of the observation;

Fig. 18.



thus, ⊙ being the observer's eye at the prism, and V the sight vane directed on an object bearing North, the *South* end of the needle lies under the prism where the observer reads 360°, the degree denoting North.

No survey of large extent could be triangulated with the Prismatic Compass when great accuracy is required. From local causes, which we have no means of ascertaining, we occasionally find that the compass gives a difference of bearing of as much as 2° or so to a line when observed from each end; and although the error is not usually so great as this, yet the possibility shows the compass to be too uncertain for the observation of an absolutely correct triangulation, but should

be merely used for filling in the details, for which purpose it is a most convenient instrument.

It is, however, sufficiently correct for the observation of military sketches of small positions, where an error of twenty yards in a mile is of no practical importance.

The whole of a sketch should be performed with the same compass; the bearings given by different compasses will be frequently found to vary as much as 3 or 4 degrees, and a party of beginners are apt to compare notes, and finding a discrepancy, to strike a mean or adopt some of the bearings given by another compass, which course will insure error. The amount of error in an instrument will not influence the correctness of the figure of the triangulation (being a constant error), provided that no other is used.

OBSERVATION OF THE TRIANGULATION.

As an illustration of the application of the Prismatic Compass for this purpose we will suppose that a position, a mile square, is to be sketched on the scale of six inches to a mile.

Having selected a base line A B, and planted conspicuous marks at the Stations C, D, E, F, G, H, K, we should go to A and observe the *bearings* of the different points, these will each be the angular distance from the magnetic meridian N S. We should note them down thus:—

At A	B	24° 30′
	C	56°
	D	102° 15′
	E	155° 45′
	F	198° 30′
	G	247°
	H	305°
	K	346° 45′

We should then pace the base A B, 679 yards, and take the bearings at B.

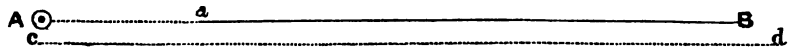
	At B	C	103°
		D	149° 30′
		A	204° 30′
		H	257° 30′
		K	293° 30′
next,	At D	C	358° 30′
		E	213° 15′
	At E	F	264°
		G	296°
	At H	F	164° 30′

This last observation is taken as the angular test; if the triangulation is correct, the line H F, when laid down on paper, will pass through the point F already fixed by bearings from A and E.

It frequently happens that, in hurried work, accidents of the ground interfere with our view of Stations from the point of observation; when this is the case, we may still obtain the observation with the compass by a little management with greater facility than with any other instrument.

The bearing of a line will evidently be the same at all points *on* that line.

Fig. 19.



If, then, finding that station B is concealed from A (the point of observation), we may walk towards B until we reach a point *a* whence the bearing can be taken.

Or we may find it more convenient to get a little on one

side of A and observe the bearing of the line *c*, *d*, parallel to A B. Either of these will be the same bearing as if observed *at* A.

If working alone, the surveyor may align himself between A and B by laying a straight walking-stick on the ground and observing its direction with regard to A and B from each end, shifting his position right or left until he finds that it will coincide with that line.

If two persons are working together they may quickly align themselves between two distant points by facing each other at about 20 yards distance apart, each dressing the other on a point, and both moving to the right or left as may be required, until each masks the distant point from the other.

Time and labour may often be saved in constructing the triangulation with the Compass, by finding the position of a Station by *Interpolation.*

It will be remarked that with regard to the bearing of a line, the angle given by the Compass at one end will be the opposite degree of the circle to that given at the other end.

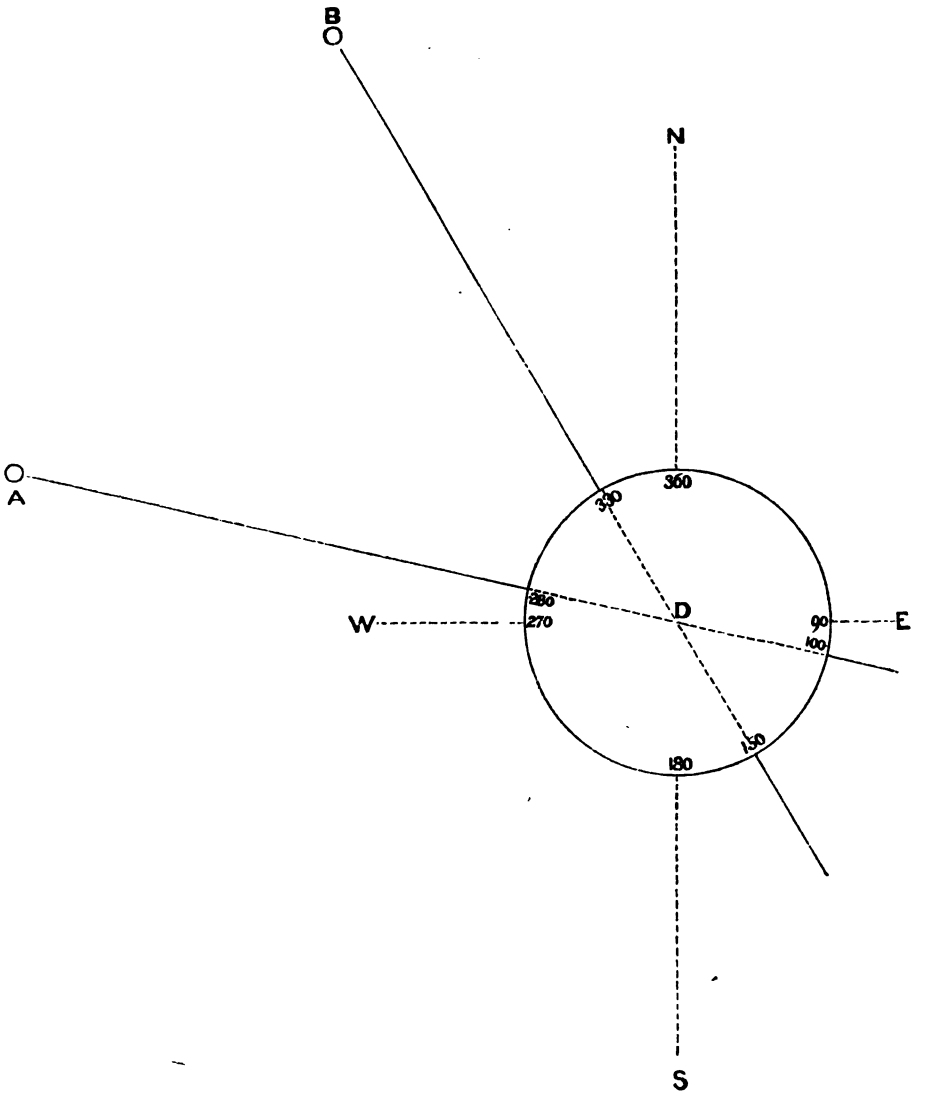
If standing at the South end of a line and observing an object exactly North, the bearing will be 360°, and we know, therefore, that if we were to proceed to that object and take the bearing of the spot at which we are standing, that bearing would be exactly South or 180°. In the same way, 90° and 270° express the same line viewed from opposite ends. This property of the Compass enables us to find the position of a Station or of any point at which we may be, when two fixed Stations are visible.

Suppose, for instance, that Station D has not been fixed, and that in observing the triangulation we find it more convenient to go there than to A and B; we here take the bearings of those two Stations A 282° 15′, B 329° 30′, and note down the opposite angles, from A, D 102° 15′ and

from B, D 149° 30′.

There is no trouble in knowing the angle opposite to that observed, as this can be seen by looking at the ivory sketching

Fig. 20.



protractor, on which each degree is numbered, with the opposite degree corresponding on an inner line.

These observations will of course be quite as correct as if actually observed *at* A and B. Not only is this method useful in finding the position of a Station, but also in every part of field sketching; for checking the accuracy of the work at any time, finding the position of a cross road or other favourable starting point, &c.

In order to find the position accurately by interpolation it is necessary that there should be a good intersection at the required point, and therefore the two Stations *from* which the place is to be found must be selected with that view. We may observe three or four Stations if we wish further to verify the position.

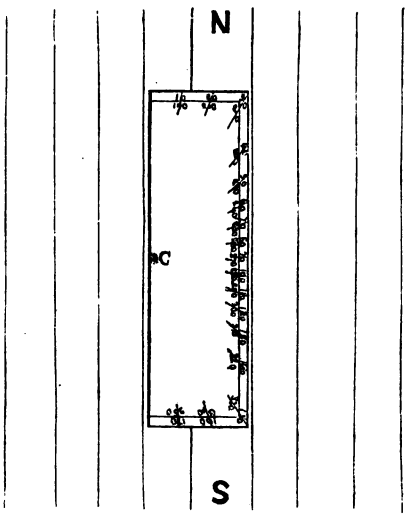
SECTION V.

LAYING DOWN THE TRIANGULATION.—MAGNETIC VARIATION.

To lay down the bearings observed with the Prismatic Compass, the ivory surveying protractor is generally used.

The degrees of the semicircle from O to 180 are marked on its outer edge, inside these the left semi-circle is continued from 180 to 360. The centre C is marked with a star or an arrow.

Fig. 21.

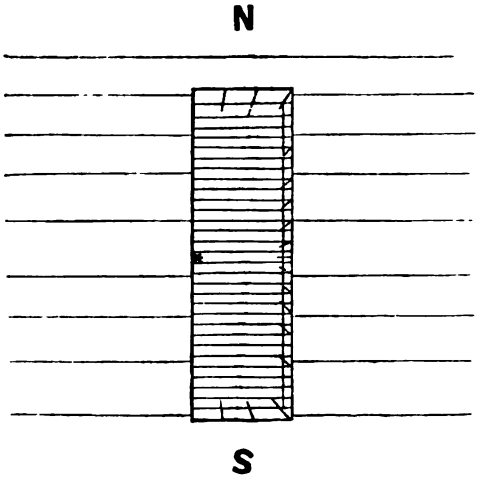


These protractors cannot be graduated to half degrees on account of their small size; when smaller quantities than degrees have to be taken, it must be done by estimation.

The paper used in sketches is ruled with light blue lines parallel to each other, about $\frac{1}{3}$ of an inch apart. These represent magnetic meridians, or North and South lines.

In laying down bearings, the protractor is adjusted North and South on the sketch as shown, with either edge parallel to or coinciding with one of these lines, there is no difficulty

Fig. 22.

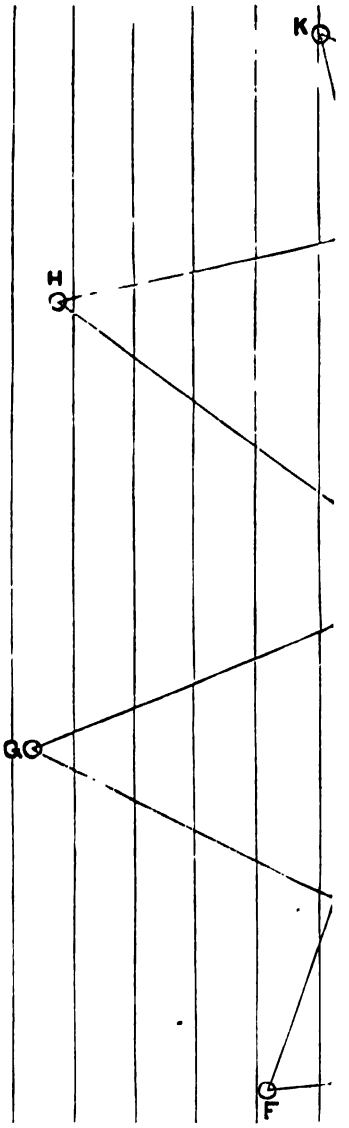


in doing this by eye.* The point C the centre of the protractor at the spot at which the bearing is to be laid down.

If the bearing is under 180° the graduated edge of the protractor should be to the East or right; if over 180°, to the West or left. Mark the required degree with a fine pointed pencil.

In order to lay down the observations of the triangulation just described. We should first draw an arrow, or print the letter N, fixing the North at the upper edge of the sketch;

* The protractor sometimes has lines engraved *across* it. Some persons prefer using the lines on the Sketching paper as East and West instead of Meridians; then the protractor is adjusted on the paper with any one of these transverse lines parallel to or coinciding with any on the sketch, and so the edges will be North and South.


K
H
G
F

that there may be no uncertainty as to the direction in which the bearings of lines are to be laid.

Having marked a suitable point for the position of A (Plate II.) we adjust the Protractor N. & S., and with its centre at that point, as shown, with the graduated edge to the right; dot off the angles under 180, viz., B 24° 30′, C 56°, D 102°, E 155° 45′, denoting each angle by its distinctive letter.

Again, adjust the protractor with its graduated edge to the left and mark off the angles over 180° as shown, viz., F 198° 30′, G 247°, H 305°, K 346° 45′.

Draw fine lines from A through these points, of an indefinite length, and on A B measure off the length of the base 679 yards at the scale 6 in. to M., this fixes the point B.

Now lay the protractor N. and S. at B, and lay off the observations C 103°, D 149° 30′, to the right, and H 257° 30′, K 293° 30′ to the left. Produce these till they intersect the relative lines drawn from A; the points of intersection determine the positions of the Stations C, D, H, K.

Rub out the unnecessary prolongations of the different lines and surround each Station by a small circle.

Next lay the protractor N. and S. at D, and lay off the bearings C 358° 30′ and E 213° 15′, these produced, verify the position of C and fix that of E.

In the same manner are laid down the bearings at E and H.

We must be careful in every case to write the name or letter of the Station on its corresponding line, otherwise confusion must arise when there are a number of lines.

The object of surrounding the Stations with a small circle is, that in extensive triangulations where a number of lines would converge at one point, none of them are produced within this ring, in order that the exact position of the Station may be preserved.

MAGNETIC VARIATION.

The direction of the true North should always be shown on a sketch.

In a combined survey performed by several persons, the chances are that no two of their compasses point to the same magnetic North. But in order to join the sketches correctly, one line, (the true North) must exist on each, common to all.

The variation of a compass is its deviation from the true North.

This differs at various parts of the globe; in the South of England, at present, the variation is about 19° 32′ West of the true North. In some places the variation is East, and at a few the compass points to the true North.

It also changes constantly. In 1580, the variation in England was 11° 30′ East, whence it gradually worked round to 24° 6′ West in 1838. Since then it has been going North again at the rate of about 7′ a year.

Every person should ascertain the variation of his compass, when he can lay down the true North by drawing a line making an angle with the magnetic meridians on his sketch, equal to the amount of variation.

This is easily found in some places where there is an observatory, and a true North point fixed in connexion with it. Otherwise, observe the bearing of the Pole Star when it is in a position vertically over the star ε of the Great Bear.

Fig. 23.

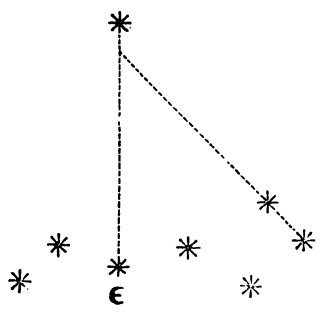
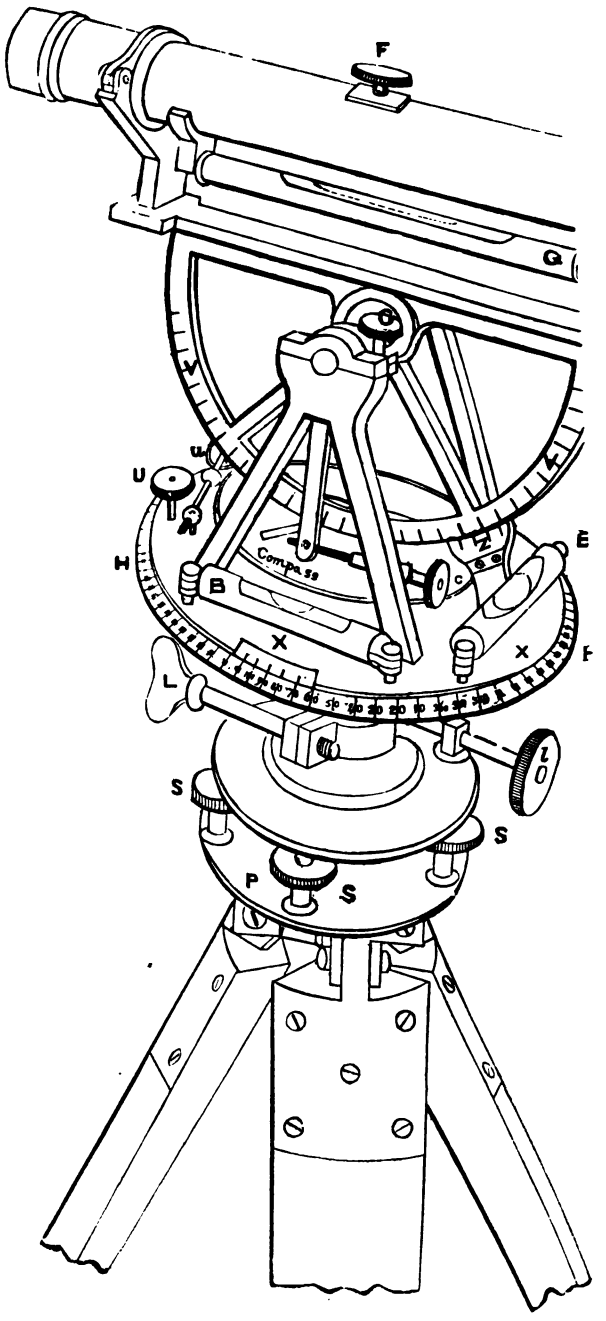


PLATE III.



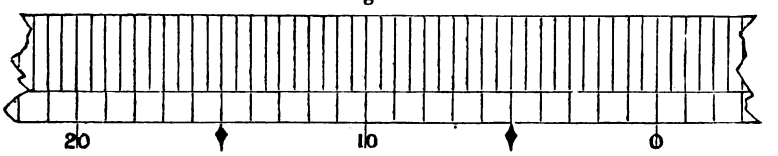
SECTION VI.

THE THEODOLITE.—MEASUREMENT OF HORIZONTAL ANGLES.—TO OBSERVE THE BEARING OF AN OBJECT.—TO OBSERVE AN ANGLE OF ELEVATION OR DEPRESSION.

This is the most perfect instrument we have for the measurement of horizontal angles.

I.—It consists of a strong metal circular plate H usually graduated on the edge into 360 degrees, and these into half degrees from Right to Left, thus:—

Fig. 24.

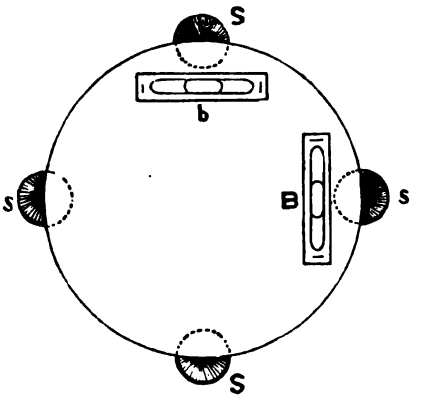


This is called the horizontal circle, it has freedom of motion in a horizontal plane, carrying with it the whole of the upper part of the instrument. Its position is regulated by the flat-headed screw L beneath it, which fixes it when tightened, by clasping its axis; and by the milled headed screw *l* which moves it slowly after being clamped. The screw L is called the lower clamping screw, and *l* the lower micrometer (or tangent) screw.

II.—The levelling screws S, four in number, by which the plate H is brought into a horizontal position. These screws are worked simultaneously *in opposite pairs*, one screwed up and the other down, until the bubbles in the spirit levels B, B, are in the centres of their glasses.

In order to act *directly* on these levels, the plate H, to which they are attached, should be turned round until each of them is parallel to an opposite pair of levelling screws B parallel to S, S, and *b* parallel to *s*, *s*. We work the screws in the required manner if we turn the thumbs either both inwards or both outwards.

Fig. 25.



III.—The upper horizontal or *vernier plate* X, which has freedom of motion on the horizontal plate H. It is so called from the two vernier scales engraved on it, which enable the observer to read the number of degrees over which it has passed on the horizontal circle. Its position with regard to that plate is regulated by the screw U which clamps them together, and the slow-motion screw *u* near it, for nice adjustment. These are called the upper clamping screw and the upper micrometer screw.

IV.—The telescope, having freedom of motion only in a *vertical* plane, and carrying with it a graduated vertical arc V for the observation of angles of elevation or depression, read by means of a fixed vernier Z. The telescope may be clamped by the screw C which tightens a collar round its transverse axis; and accurately adjusted by the micrometer screw *c*. The focus of the telescope is regulated by the milled-headed screw F, and the eye-piece is moved in and out until the cross hairs inside the telescope are seen sharp and distinct. The axis of the telescope, on which the cross hairs should intersect, is called the *line of collimation*. It has a spirit level G attached to it, chiefly used in levelling operations.

V.—The compass box, containing a magnetic needle balanced on a pivot, to indicate the azimuth.

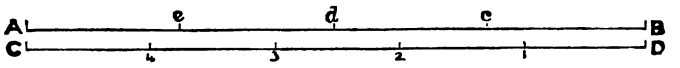
The most important part of the Theodolite is the horizontal circle H. In the small Ordnance Theodolites its diameter is 5 inches, whence it is known as the 5-inch Theodolite, but they are made of many different sizes, ranging from a horizontal circle of 3 to 36 inches diameter.*

THE VERNIER.

The vernier scale is a contrivance for subdividing a graduated scale into fractional parts. Its principle is this:—

If a line A B be divided into any number of equal parts, say 4; and a line of equal length C D be divided into 5,

Fig. 26.

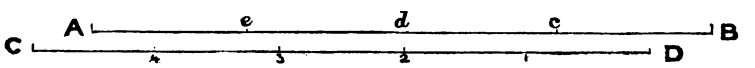


Then, each division in C D will be smaller than each in A B by $\frac{1}{5}$th; and C D will be a vernier scale to read fifths of the primary divisions.

If the line C D be moved along A B until the division 1 coincide with *c*; D will have passed over $\frac{1}{5}$th of a primary division from B.

If the vernier scale be moved until 2 coincides with *d*

Fig. 27.

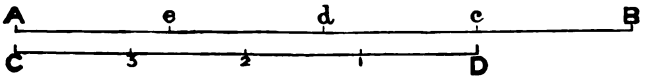


D will have passed over $\frac{2}{5}$ths of a primary division from B, and so on.

* No mention has been made of the adjustments which the Theodolite requires from time to time to keep it in perfect working order; these are somewhat complicated, and it is needless to perplex the beginner with them.

To construct a vernier to read fourths of the same primary divisions. Take a line C D equal to three of these A *c*.

Fig. 28.

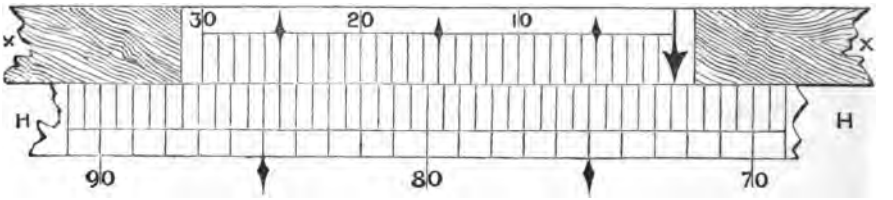


Divide it into 4 parts, each of these will be $\frac{1}{4}$th less than each of the primary divisions; and if the vernier scale C D be moved, the successive contacts of 1, 2, and 3, with the primary divisions *d*, *e*, A, will indicate how many fourths D has moved from *c*.

In the 5-inch Theodolite the vernier scale on the upper horizontal plate X is constructed to subdivide the divisions of the horizontal circle (each equal to $\frac{1}{2}$ a degree or 30 minutes) into minutes; therefore an arc equal to 29 of these primary divisions is taken and divided into 30 equal parts, each of which is $\frac{1}{30}$th (or one minute) less than the divisions of the horizontal circle.

Fig. 29.

Vernier Scale.



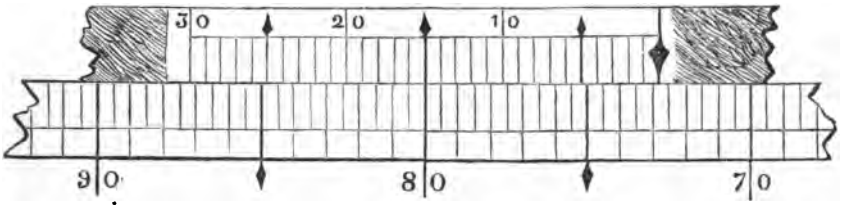
To read off the angle recorded by the vernier. First look at the zero or arrow of the vernier, and notice what degree of the lower plate it has last passed (from right to left). In the figure this is 72 degrees. Now examine the divisions of the vernier to find the minutes. We find that only one exactly coincides with one on the lower plate (the 23rd). The angle then is 72° 23′.

But if the zero of the vernier has passed one of the half degrees of the lower plate, as in the accompanying figure,

we must add the number of minutes denoted by the coincidence of the lines on the vernier and lower plate, to the 30

Fig. 30.

Vernier Scale.



minutes or $\frac{1}{2}$ degree already recorded by the zero of the vernier. Thus, as the vernier shows 15 minutes, the angle recorded is 72° 45′.

The Theodolite has this great advantage over other instruments, that, having motion only in a horizontal and a vertical plane, the angles observed are always *true horizontal angles;* and if we measure a round of angles to Stations at different levels, and complete the circle, the sum of these angles will be 360°.

MEASUREMENT OF HORIZONTAL ANGLES.

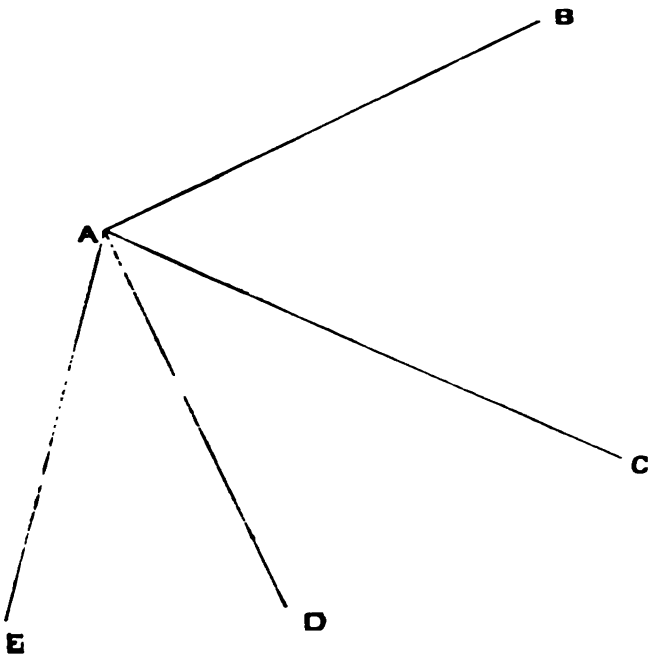
Let A be the Station at which we wish to measure the horizontal angle between B and C.

I.—Set up the instrument exactly over the Station A with the legs about a yard apart, and firmly pressed into the ground, at the same time endeavouring to place them so as to set the horizontal circle tolerably level. A small stone dropped from underneath the instrument, or a plumb line, will show if it is vertically over the Station.

II.—Release the lower clamping screw L (Plate III.) and turn the head of the instrument until each of the spirit levels is parallel to an opposite pair of levelling screws, and act upon them as described.

It will probably occur that levelling by the second pair of screws will slightly disarrange the plane levelled by the first

Fig. 31.



pair, in which case we must return to them. The levelling screws have a limited action, and will jam, unless the horizontal circle be placed fairly level by the position of the legs. These screws must all touch the plate P, else the head of the instrument will be ricketty; but no force must be used in this or any other adjustment.

III.—Both clamping screws L and U being free, turn the vernier plate X so as to bring the zero of the vernier to coincide with the zero or 360° of the horizontal circle H as nearly as can be done by hand; clamp upper clamping screw U and adjust the coincidence exactly by upper micrometer *u*.

IV.—The telescope being brought into good focus, and the cross hairs distinct, turn the whole head of the instrument

until the telescope is directed on the *left hand* object B; clamp the lower clamping screw L, and by means of the lower micrometer screw *l*, bring the intersection of the cross hairs exactly on that object. The instrument should now be examined to observe the accuracy of the three adjustments that have been effected.

1st. That the bubbles of the spirit levels are in the centres.

2nd. That the zero of the vernier coincides with zero of the horizontal circle.

3rd. That the cross hairs intersect the left hand object.

V.—Release the upper clamping screw U and turn the telescope on the right hand object C; clamp, and perfect the intersection of the cross hairs by the upper micrometer *u*. We may then read off the required angle recorded by the vernier, being the number of degrees and minutes over which the upper plate has passed. The vernier scale at the opposite side should also be examined, and the mean of the minutes adopted, if there should be any difference in the number recorded.

If a round of observations is to be made, the lower clamping and micrometer screws must remain undisturbed, and the cross hairs of the telescope brought on each Station, D, E, &c. in succession from left to right by the upper clamping and micrometer screws. The angle recorded will in each case be the angular distance from B.

If we have reason to doubt the correctness of the graduation of the instrument, or of its centring, the best method of obviating any error that would arise from these causes, is to observe the angle by repetition, that is, instead of releasing the plates and re-adjusting the zeros for a fresh observation, leave them clamped together at the observed angle, release

the lower clamping screw L, and turn the whole head of the instrument again on the left hand object, using only the lower clamping and micrometer screws,—then unclamp the vernier plate and direct the telescope on the right hand object, the recorded angle will be double the true one. Again, turn the whole head of the instrument on the left hand object with this last position of the plates clamped, and repeat the operation, the observed angle will be three times the true angle.

The angle may also be observed by directing the telescope on the left hand object with the plates clamped together indifferently at any angle; and the difference between this and the angle, recorded by the vernier when the telescope is directed on the right hand object by the upper screws, will be the required angle.

TO OBSERVE THE BEARING OF AN OBJECT.

Set up the Theodolite as already described, level, and with the plates clamped together at zero. Release the magnetic needle by turning the trigger at the side of the compass box, turn the head of the instrument round until the 360° or zero* engraved inside the compass box is brought opposite the North end of the needle, clamp and perfect this adjustment (lower clamping and micrometer screws). Release the vernier plate, and intersect the object by the cross hairs (upper clamping and micrometer screws). The bearing or azimuth angle will be recorded by the vernier on the horizontal circle.

* If the instrument is in proper adjustment it will be found that the zero of the vertical arc and its vernier zero will coincide, when the bubble in the spirit level G is brought to the centre of the glass by the clamping screw C and the micrometer *c*.

TO OBSERVE AN ANGLE OF ELEVATION OR DEPRESSION.

For this observation, the relative position of the plates is immaterial, provided that they are level.

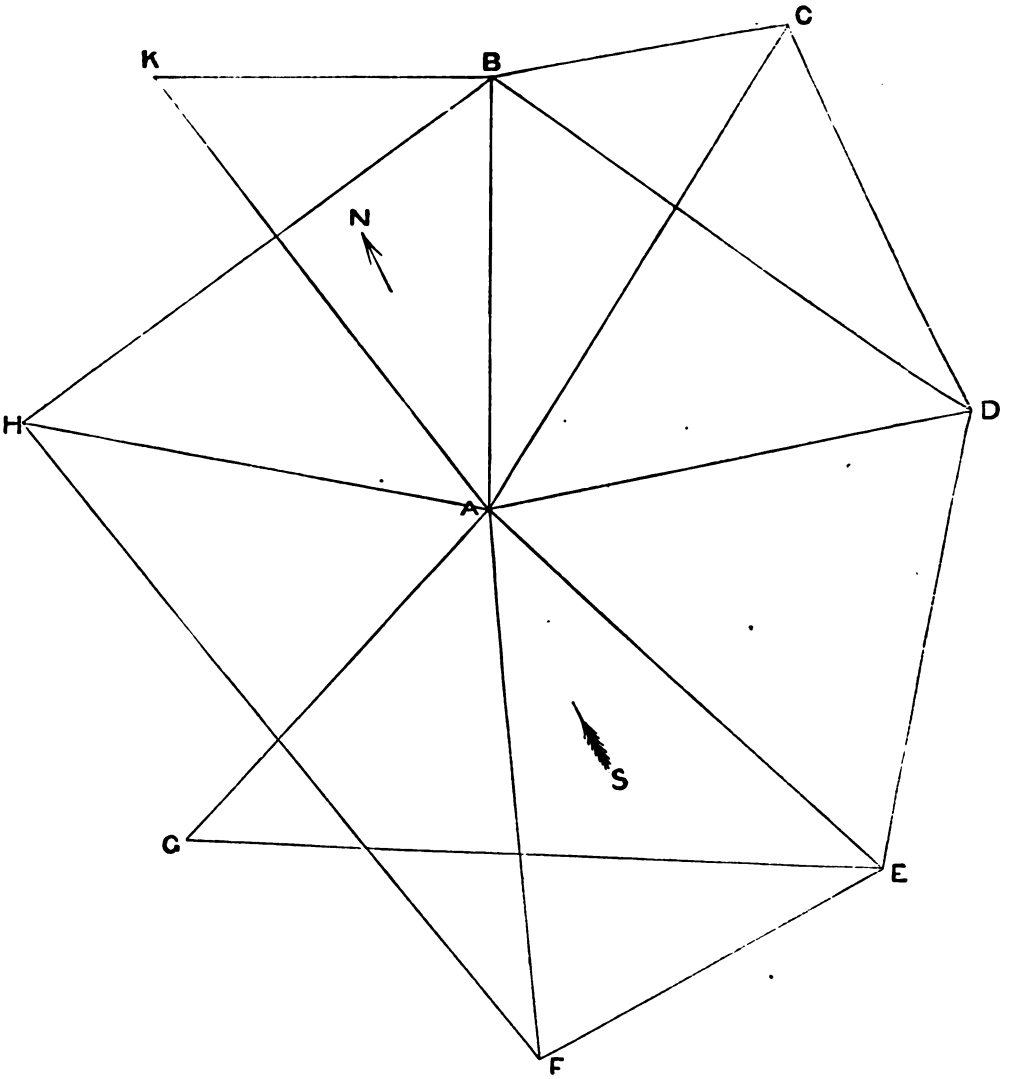
Intersect the object by the cross hairs, using for this adjustment the clamping screw C and micrometer *c*, and read the angle indicated by the vertical vernier Z, which, it will be observed, is engraved so as to read either from right to left, or *vice versa*, the former for angles of depression, the latter for elevation.

When great accuracy is required, remove the telescope from its Y's, and reverse its position for the second observation, taking the mean of the readings as the true angle.

At the reverse side of the vertical arc is engraved a scale, showing the number to be deducted from every hundred measured, whether in yards or links, on sloping ground, to reduce the measurement to its true horizontal length.

PLATE IV.

To face p. 43.



SECTION VII.

OBSERVATION OF THE TRIANGULATION.

As an example of the application of the Theodolite for this purpose, we will suppose that the same triangulation described as surveyed with the Prismatic Compass, is to be observed with the Theodolite.

Set up the instrument at A level, and with the zeros coinciding for the observation of horizontal angles (Page 37). Direct the cross hairs on B, and observe the round of angles from left to right, entering them in the Field Book, thus:—

	At A.	Angle.
From B to C . . .	30° 4′ . . .	B A C
„ to D . . .	76° 14′ . . .	B A D
„ to E . . .	131° 42′ . . .	B A E
„ to F . . .	174° 2′ . . .	B A F
„ to G . . .	222° 31′ . . .	B A G
„ to H . . .	280° 58′ . . .	B A H
„ to K . . .	322° 47′ . . .	B A K

After completing the observations, direct the telescope on B, and observe that the zero of the vernier has returned to 360° of the horizontal circle, showing that the instrument has not been disturbed.

Should it be necessary to observe the angles by repetition, we should enter them thus:—

	At A.			
	1st Obsern.	2nd Obsern.	3rd Obsern.	Mean.
From B to C .	30° 5′	30° 3′	30° 4′	30° 4′
From B to D .	76° 13′	76° 15′	76° 14′	76° 14′

In so small a triangulation as that here described, however, the precaution of reading both verniers at the opposite sides of the vernier plate and adopting the mean, is sufficient.

Besides the angles mentioned here we may observe any others to points which *may*, perhaps, fall within the triangulation, this may obviate the necessity of returning subsequently.

Whilst at B adjust the Theodolite, to observe the bearing of the base A B, 24° 15′.

The instrument is then removed to B, and a round of angles observed, measured *from A*.

	At B.	Angle.
From A to H . . .	52° 32′ . . .	A B H
„ to K . . .	89° 1′ . . .	A B K
„ to C . . .	259° 56′ . . .	A B C
„ to D . . .	305° 7′ . . .	A B D

No angles are here taken to E, F, or G, as they would produce too acute intersections at those Stations; these are left to be determined by a second series of triangles.

The bearing of the base B A is again observed, 204° 30′, differing 15′ from the bearing taken at A; the mean is adopted, 24° 22′.*

The difference of 15′ seems at first like a serious error when we are using so perfect an instrument as the theodolite; it must be remembered, however, that the magnetic needle is not to be regarded as an integral part of the instrument, but merely a convenient addition of one possessing minor claims to accuracy; the needle being subject to such disturbing influences as the presence of iron ore in the ground; the

* The bearing 24° 22′ and 204° 22′ express the same line viewed from each end. (Page 26).

vicinity of any iron work, such as rails, gates, &c.; magnetic disturbances in the atmosphere, &c., besides the diurnal variations which take place at different times of the day, averaging from about 6 to 13 minutes, the maximum being about 25 minutes. There is also the practical impossibility of adjusting the head of the instrument so as to bring the zero in the compass box into *exact* coincidence with the North end of the needle, or nearer than about $\frac{1}{4}$ of a degree.

For these reasons the use of the needle is avoided as much as possible when extreme accuracy is required.

An inaccuracy in the bearing of the base (*i.e.*, the relation of the meridian to the triangulation) in no way affects its form, if observed in the manner described here, in which we are quite independent of the meridian.

The requisite observations having been made at both ends of the base, the Theodolite is removed to D, and the following angles measured.

	At D.	Angle.
From A to B . . .	48° 53′ . . .	A D B
„ to C . . .	80° 4′ . . .	A D C
„ to E . . .	290° 5′ . . .	A D E

The angle A D B is observed for the sake of proving the accuracy of the other angles of that triangle already observed, as their sum will be 180° if correctly taken. This precaution of observing all three angles is taken with all the primary triangles of a triangulation that is meant to be extended; this is known as the "triangular test." *

The angle A D C is observed as a check on the accuracy of

* When the triangles are of great size, the sum of the three angles will exceed 180° by a few seconds, in consequence of the triangles being described not on a plane but on a sphere; this is called "spherical excess." The quantity, however, is so small as not to be detected by the 5-inch Theodolite.

the Station C which has already been fixed from the ends of the base A B.

The angle A D E intersects the line A E and fixes E, which was badly situated for intersection from both ends of the original base.

The Theodolite is next set up at E.

	At E.	Angle.
From A to D	54° 37′	A E D
„ to F	288° 30′	A E F
„ to G	320° 44′	A E G

Here the angle A E D gives the third or supplementary angle in that triangle, and E F and E G intersect the lines A F, A G, and determine G and F. Next

	At H.	Angle.
From B to A	48° 26′	B H A
„ to F	87° 50′	B H F

Here, B H A is the supplementary angle, and B H F an additional check on the Station F already fixed "the angular test,"—or if the triangulation be laid down by calculation, we have two values of the line A F, derived on one side of the original base from the successive bases A D, A E, and on the other from A H; if these calculated lengths correspond, the accuracy of the whole is certain.

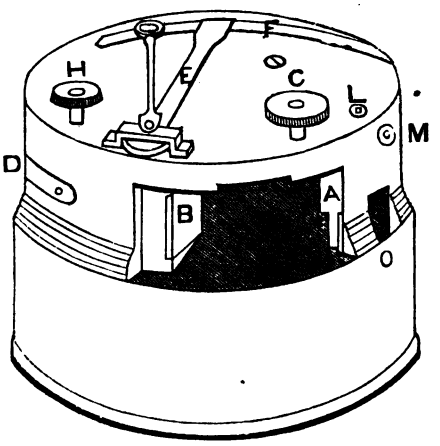
A diagram of the triangulation should be made on a small scale in the field, as it proceeds, that its form may be thoroughly understood, and that no necessary observations may be omitted.

SECTION VIII.

THE POCKET SEXTANT.—OBSERVATION OF THE TRIANGULATION.

This instrument combines so many valuable qualities that it may fairly be considered indispensable in military surveying. It approaches the Theodolite in accuracy, measuring angles to a minute, and is only about 3 inches in diameter and $1\frac{1}{2}$ inches deep. Observations may be taken with it with rapidity and certainty even from horseback, or when subject to the action of high wind. It is also safe from injury and easily put in adjustment.

Fig. 32.



The Sextant is represented with its cover screwed on underneath it, as it should be when in use. At other times, the cover being screwed down over the face effectually excludes dirt and dust, and protects it from accidental injury.

It does the work for which it is designed admirably, viz.,—

the measurement of horizontal and vertical angles, but is not so generally useful as the prismatic compass, being inapplicable to the filling in of details, &c.

The Sextant is one of that class of instruments called reflecting instruments, wherein mirrors are used. It contains two, A and B. The mirror A, called the horizon glass, is fixed perpendicular to the plane of the instrument, the upper half only of this glass is silvered, the lower and transparent half is opposite the opening O. The mirror B, called the index mirror, moves by turning the milled-headed screw C, which communicates with it by a rack and pinion movement in the interior; it carries with it the index arm E, which is provided with a vernier scale reading minutes on a graduated arc F, inlaid on the face of the instrument. This arc is graduated in the same manner as the horizontal circle of the Theodolite, except that it is numbered from left to right and consists only of about 120°. The vernier scale is also numbered from left to right.

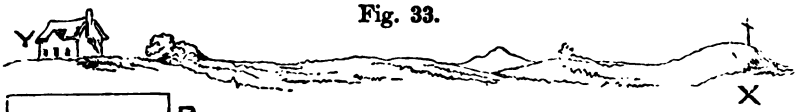
At D there is a slide in some instruments, with coloured glasses, which may be interposed when a solar observation is taken; and at the far side of the instrument, which cannot be shown in the figure, is an opening in the box, at which are two levers, by means of which other coloured glasses may be interposed in the interior for the same purpose.

To observe an angle with the Pocket Sextant. Screw in the telescope with which most are provided at D, or, if unprovided with a telescope, draw aside the coloured glasses in the slide and look through a small hole there at the *left hand* object Y through the opening O.

Hold the lower part of the Sextant with the left hand, and with the right turn the screw C (raising the right elbow high so that it may not interpose between the instrument and the right hand object) until the right hand object X is reflected by the index mirror B to the upper or silvered half of the

horizon glass A, and appears in coincidence with the left hand object Y, Fig. 34. (seen by direct vision through the lower or

Fig. 33.



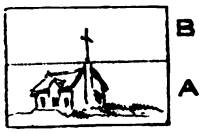


Fig. 34.

transparent half of that glass). The angle may then be read off the vernier by the magnifying glass.

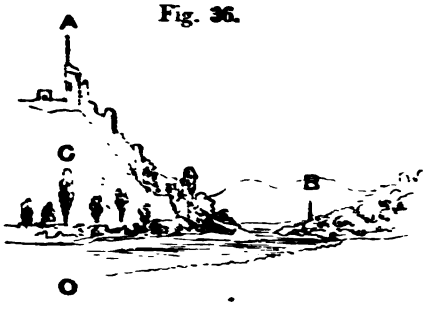
The chief point of inferiority of the Sextant and the Theodolite is this. In the Theodolite, the angle observed is in every case the true horizontal angle, by the construction of the instrument. But in the Sextant, in order to bring the reflected image into coincidence with that seen by direct vision, it is necessary to hold the instrument so that its plane is parallel to that of the two objects.

Fig. 35.

The observed angle will in this case be greater than the true horizontal angle, one object being at a higher level than the other.

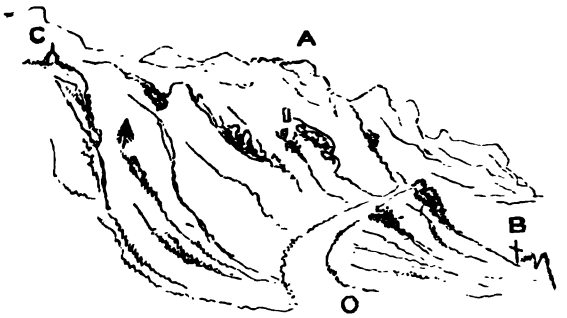
In order to overcome this defect, O being the point of observation, select some point C, either vertically over or under one of the objects, and nearly in the same horizontal plane as the other, and observe the angle C O B between these, instead of A O B.

Fig. 36.



The nearer the two objects are to each other, the greater will be the error in the observed angle produced by a difference of level. Another method of avoiding this error

Fig. 37.



is, to select a point C 90° or 100° distant, and observe the angles between each of the objects and that point, C O A, C O B. The difference between these will be more nearly the true horizontal angle.

The Pocket Sextant will not measure an angle greater than about 120°. When the angular distance is larger than this, we should select a point lying between the objects, and observe the angle lying between it and each of them. The sum of these will be the whole angle.

We frequently find that objects distinct enough when viewed with the naked eye, become invisible when the Sextant is used, and that those which have a background of sky are most

distinct. We should, in this case, *make* the clearest object, that which is reflected by the index glass, as the less distinct object may still be seen by direct vision. When the clearest object is on the left the Sextant may be held upside down and the left hand object brought to the right.

To observe a vertical angle. Hold the Sextant in the right hand with its face to the left, and, looking at the lower object by direct vision, bring the upper down into coincidence with it, using the left hand to turn the screw C.

Before proceeding to take angles with the Pocket Sextant, we should ascertain whether it is in perfect adjustment. The points to be observed are two.

1st. That the two mirrors are parallel to each other when the zero of the vernier coincides with that of the graduated arc.

2nd. That the horizon glass is perpendicular to the plane of the instrument.

For the first of these, select a well-defined object, such as the angle of a house, or a pole, about $\frac{1}{2}$ a mile distant, and bring the reflected and the direct image of this into coincidence; then examine the vernier, and if it is at zero the instrument requires no alteration; if it does not coincide with zero by a few minutes, note down the angle recorded as the "index error," to be added to or subtracted from all observed angles. If the zero of the vernier rests at, say, 5′ to the right of the zero of the arc, we note it as "index error + 5," and subtract that quantity from all observed angles. If it rests at the left of the zero (called the arc of excess), we ascertain the angle so recorded by counting for minutes on the vernier as if it were numbered the reverse way, from right to left. This quantity is noted as "index error minus −" and is to be *added* to all observed angles.

If the index error be very great, we may adjust the instrument so as to correct it. Place the two zeros in coincidence, remove the key H, apply it to the square at M, and turn

t until the direct and reflected images coincide exactly. This adjustment need not be frequently effected: if the index error is small, it is simpler to take note of it as a constant error, as described.

The other adjustment (to correct the perpendicularity of the horizon glass to the plane of the instrument) is effected by observing whether the reflected and the direct images of the distant horizon appear as *one*. If two horizons appear, we apply the key at L, and turn it till they agree.

By turning down the coloured glasses, and bringing the reflected and the direct images of the sun together, we may satisfy ourselves of the correctness of both adjustments of the Sextant at once, if the vernier reads 0 on the graduated arc.

The adjustments of the Sextant are tested by observing a distant object: because at short distances, under 100 yards or so, the parallax of the instrument becomes apparent. Instrumental parallax expresses the error caused in observations of near objects by the necessity of placing the eye *at one side* of the index mirror. Were it possible to observe the angle from the real centre there would be no such error. As it is, it is very small, and at 150 or 200 yards is inappreciable.

As, at present, the application of the Pocket Sextant to triangulation *only* is being described, no mention is here made of many other uses to which it may be applied, such as the measurement of the heights of buildings, &c.

OBSERVATION OF THE TRIANGULATION.

The angles observed with the Sextant are, as with the Theodolite, the angular distances between *visible* objects, differing from the Prismatic Compass which gives the angular [illegible] from an *imaginary line*, the magnetic meridi[illegible]

In observing the triangulation (Pla[illegible] Sextant, firstly observe the round[illegible]

Station C to coincide with B, and read the angle B A C 30° 4′. Next bring D to B, the angle B A D = 76° 14′. We find that the next angle B A E is greater than can be measured by the Sextant, observe instead D A E 55° 28′ (the angular distance of D from B being known), also D A F = 97° 48′.

Complete the observations by the angles K A B, H A B, G A H, F A H, taking care in every case to measure either from or to a Station, the angular distance of which from the other end of the base B has been already measured.

The angles would be entered in the Field Book, thus:—

At A	from B to C . . .	30° 4′
	„ to D . . .	76° 14′
	D to E . . .	55° 28′
	„ to F . . .	97° 48′
	K to B . . .	37° 13′
	H to B . . .	79° 2′
	G to H . . .	58° 27′
	F to H . . .	106° 56′

If the Stations are situated nearly in the same horizontal plane, or if proper care has been taken to avoid oblique observations as described, the sum of the whole round of angles should be 360° within a few minutes.

A diagram of the figure of the triangulation should be made in the field, in order to guard against the omission of any necessary observation.

The bearing of the base A B should be taken at the same time, with the prismatic compass, 24° 15′.

The next series of angles would be observed at B, and measured either to or from the known point A.

At B	from A to H . . .	52° 32′
	„ to K . . .	89° 1′
	D to A . . .	54° 53′
	C to A . . .	100° 4′

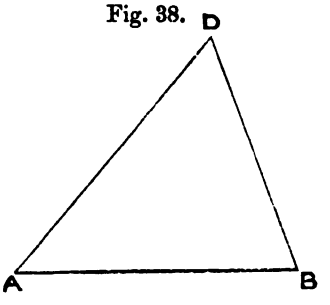
Next, At D	from A to C . . .	80°	4′
	E to A . . .	69°	55′
At E	from F to A . . .	71°	30′
	G to A . . .	39°	16′
At F	from H to A . . .	38°	40′

This last observation is taken in order to apply the angular test, if the line F H, when laid down on the plan, be found to pass through H, already fixed, we may conclude that no great error has taken place in observation or construction.

When a Station is fixed by an acute intersection, its position should be verified by several observations in this way.

As the third angle of any triangle is the supplement of the others, it is immaterial which two angles we observe, and it occasionally may save time to observe the second angle at the vertex in preference to the other end of the base. For instance, in the triangle A B D, having observed at one end of the base the angle D A B = 49° 6′, we might find it convenient to observe the second angle at D instead of at the other end of the base B. Then A D B being 50° 20′, we have the two angles 49° 6′ + 50° 20′ = 99° 26′; and 180° − 99° 26′ = 80° 34′ the angle A B D.

Fig. 38.

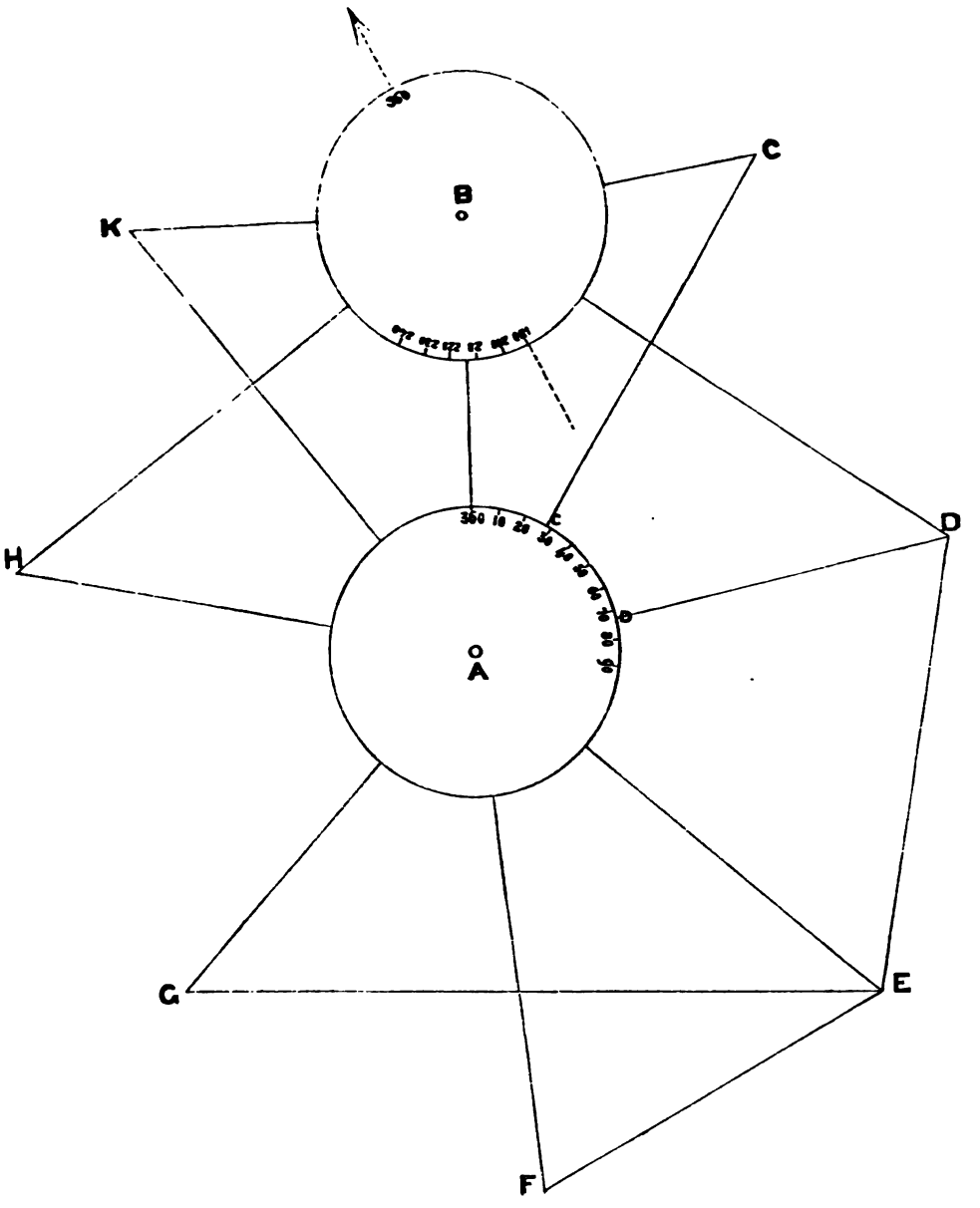


It may sometimes be found easier (when the triangulation is not intended for calculation) to measure the angular distance from some Station already fixed, although not belonging to the same series of triangles, in preference to the latter.

For instance, when at E, (Plate IV.) wishing to observe the direction of F and G, we might find it easier to observe the angles between these points and H, instead of A, if the latter were obscure or not in the same horizontal plane.

PLATE V.

To face p 55.



SECTION IX.

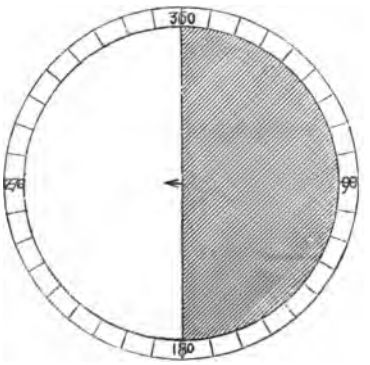
CONSTRUCTION OF THE TRIANGULATION.—SCALE OF CHORDS. BY CALCULATION.

When the triangulation observed with the Theodolite or Pocket Sextant is to be laid down by construction, a larger protractor than the common sketching protractor must be used, in order to lay down the angles with accuracy, proportionate to the nicety of the observations.

Of the many forms in which they are manufactured, it will be sufficient to describe the printed cardboard protractor, which will probably be that used by the beginner.

These are made in sizes varying from about 12 to 18 inches diameter, and are graduated to as small as 15′, so that angles

Fig. 39.



may be laid down by estimation within 5′. A small hole should be cut out at the centre for the convenience of adjust-

ing them to any point on the plan: these protractors are very useful, both for constructing the triangulation and for plotting the details.*

In laying down the triangulation we merely repeat with the protractor the observations taken, by adjusting the centre to the point *at* which, and the zero towards the point *from* which, the measurements were taken: mark off the position of the angles, and produce them to intersection as described.

A point A having been assumed on the plan, A B is drawn in any convenient direction, 679 yards long, scale 6 inches to a mile.

The first observations in the Field Book (Page 43) being

At A	from B to C . . .	30°	4′
	„ to D . . .	76°	14′

The protractor is shown adjusted with its centre at the point A, and the zero coinciding with A B, the direction of C and D is marked off with a fine pointed pencil.

The next observations being,

At A	from D to E . . .	55°	28′
	„ to F . . .	97°	48′

the zero must now be adjusted to the line A D, and the directions of E and F marked, &c.

If the triangulation is to be constructed on paper already prepared with meridians, the base must *first* be laid down in its proper relation to them, and the construction of the figure then proceeded with.

* The circular cardboard protractors sometimes have a piece of the shape shown by the shaded portion cut out and the centre marked. They are also made in the form of a ring, when the centre has to be found by laying a straight edge across the diameter from 90° to 270°.

If on plain paper, the direction of the meridian may be laid down after the figure has been constructed. The protractor is adjusted for this purpose with its centre at the point of observation, and the observed bearing in coincidence with the base or other observed side: the zero then indicates the North, and 180 South. These points should be permanently marked, and all meridians required in the course of the work are referred to them.*

The protractor B is shown in Plate V. adjusted at B, to lay down the meridian, the observed bearing of A from B being 204° 15′.

SCALE OF CHORDS.

Many protractors have the scale of chords engraved on them, by means of which considerable accuracy may be obtained in constructing the triangulation.

* There are many varieties of protractors furnished with verniers, with which a higher degree of accuracy is supposed to be obtained. These are of metal, either circular or semi-circular in form, the centre usually marked by a fine cross on glass. They are provided with a radial arm carrying a vernier scale, capable of being adjusted to a minute on the graduated circumference; this arm generally extends to some inches beyond the circle, its edge being the prolongation of the radius. The vernier is set at the required angle and clamped before the protractor is adjusted on the plan.

Circular protractors are also made with points on the reverse side to fix them on the paper; they have two radial bars, at the extremity of one of which is a vernier scale for adjustment on the graduated circumference, and, of the other, a pinion working in a toothed rack round the instrument; both arms are provided with a pricker, by which the position of the required angle is marked on the paper. This instrument, however, does not find much favour among surveyors, on account of the manner in which it defaces the paper, and because it is delicate and easily put out of order.

Circular and semi-circular protractors of different sizes, with less pretension to accuracy, are made of metal, graduated to as small as 20 minutes, without vernier. I prefer the cardboard to most of these, being less tiresome to the eyesight; whilst sufficiently accurate.

To set off an angle. With the point of observation as a centre, describe an arc with a radius of 60 degrees taken from the scale of chords.

On this arc set off the angular distance (taken on the scale of chords), from its point of intersection with the base; a right line produced through this point from the point of observation, is in the required direction.

BY CALCULATION.

When the survey is of any great extent the triangles should be laid down by the length of their side found by calculation, instead of by their angles; by this method a much higher degree of accuracy may be obtained. In a survey of from 10 square miles upwards, at any rate, some of the principal Stations should be so determined.

For the solution of triangles in surveying, we require to know the length of one of the sides, and two of the angles, or two sides and the angle contained between them; and as the former is more simple in calculation and in observation, it will be that which will be almost invariably given.

For this the rule is, that, *the sides are proportional to the sines of the opposite angles.*

In the triangulation, Page 29, we know in the triangle A B D the length of A B = 3086 links, the angles B A D 76° 14′, A B D 54° 53′, and A D B 48° 53′.* To find the length of A D (or b).

sin. D : sin. B : : d : b

by natural sines $b = \dfrac{d \text{ sin. B}}{\text{sin. D}}$.

by logarithms $\text{L}\, b = \text{L}\, d + \text{L sin. B} - \text{L sin. D}$

$= 3{\cdot}489396 + 9{\cdot}912744 - 9{\cdot}877010 = \text{L}\, b.$

* If two angles A and B only had been observed, the third D would be their supplement,

$$\text{D} = 180° - (\text{A} + \text{B}).$$

If a large number of triangles are to be calculated, they may be arranged in a convenient tabular form, using the cosecant of the angle opposite the known side instead of the log sine; then all the calculations are additive.

A	Angles.	Angles.	Logarithmic Computation.	Distance.	Side.	Remarks.
	„	„	3·489396	3086	A B	Base.
◁	A D B	48° 53′	0·122990	„	„	cosecant.
A	A B D	54° 53′	9·912744	„	„	sine.
B	B A D	76° 14′	9·987341	„	„	sine.
D			3·525130	3351	A D	
„			3·599727	3979	B D	

In this form we have the first two logs common to both sides, and if we cover the quantity not required (the third or fourth) with a slip of paper, the addition is easily made or revised.

In the other case, if we know two sides and the contained angle—

Let the known side be f 1076·53, and e 2846·39, and B the contained angle 150° 7′. To find the other quantities:—

The sum of the angles opposite the given sides is found by subtracting the given angle from 180°, E + F = 180° − 150° 7′ = 29° 3′.

and $\frac{1}{2}$ (E + F) = 14° 31′ 30″.

The sum of the two sides is to their difference, as the tangent of half the sum of the angles at the base, to the tangent of half their difference.

Ar. co. Log. $(e + f)$ 3922·92 = 6·406347

Log. $(e - f)$ 1769·86 = 3·247939

Log. tan. $\frac{1}{2}$ (E + F) 14° 31′ 30″ = 9·413205

Log. tan. $\frac{1}{2}$ (E − F) 6° 39′ 46″ = 9·067491

Hence, E = 21° 11′ 16″ and F = 7° 51′ 44″.

To find the required side *b*.

Log. cosec. E 21° 11′ 16″ =	10·441982
Log. sin. B 150° 57′ =	9·686254
Log. *e* 2846·39 =	3·454296
Log. *b* 3824·12 =	3·582532

In laying down triangles by their sides we describe arcs of the required length of radius from both ends of the base, their intersection gives the required Station.

Beam compasses are employed for this purpose. This instrument is a beam of well-seasoned wood with the required scale engraved on a slip of holly or box-wood inlaid upon it. It is provided with two boxes fitting to and moveable on it, each of these has a vernier scale and a clamping screw, also needle points coincident with the zeros of the verniers.

As a substitute for this (when the required length is greater than can be taken in the opening of common compasses) we may use a slip of stout paper with two holes at the required distance, one adjusted to the centre by a needle, the other guiding a fine pointed pencil in describing the arc.*

* It will be well to test the accuracy of the length of the sides when we are unprovided with proper beam compasses, by laying the Marquois scale in an upright position on each in the manner described (Page 5, note), when the calculations are made in links, and the plan scale is suitable to one of the Marquois scales as described.

SECTION X.

TRAVERSING WITH THE THEODOLITE AND CHAIN.

FIELD BOOK.—TRAVERSING.—PLOTTING, ETC.

Having completed the triangulation, the next step will be to traverse the roads, boundaries, &c., and either fill them in on the sketch at the time, as is usually done in small surveys; or else record the measurements in a Field Book, from which notes the survey may subsequently be plotted at leisure.

This latter system is adopted when the survey is on a large scale, or great accuracy required, or where a permanent detailed record of the measurements is desirable.

The Field Book has a column ruled lengthways down the centre of each page, this column represents the chain itself on the line along which it passes in measuring.

The only entries made in this column are *the forward measurements and their direction.*

The side columns are called the right and the left offset columns; in them are entered the width of the road on each side of the chain line; the position and form of all houses, fences, &c., as we pass them; and the angles taken to objects lying off the traversed line.

An offset is a measurement taken perpendicular to the forward angle; this is one of the most important processes in surveying, and by this means the form of most objects is investigated.

The order in which the entries are made in the Field Book is the reverse of the ordinary method; for we commence at

the end of the last page and continue upwards and towards the beginning of the book.

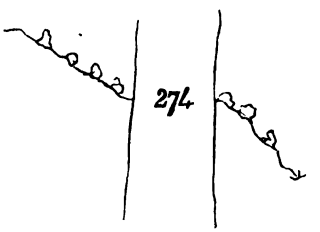
When traversing, the Field Book must be always held so that the direction of the chain column coincides with that in which we are going; then no mistakes can occur in entering the details on the right and left in their respective offset columns.

Each entry must have a separate line devoted to it, and the offset entries must be made on the same line as the forward distance in the chain column opposite which they occur.

The position and true form of all objects is denoted in the offset columns *entirely by the figures* recording the measurements taken, and no object need here be drawn to any particular scale: conventional signs somewhat explanatory of their forms are entered, and we usually exaggerate the peculiarities of shape of houses, irregular fences, &c., in the offset columns, in order to convey a clear idea of the particular measurements to which the accompanying figures refer.

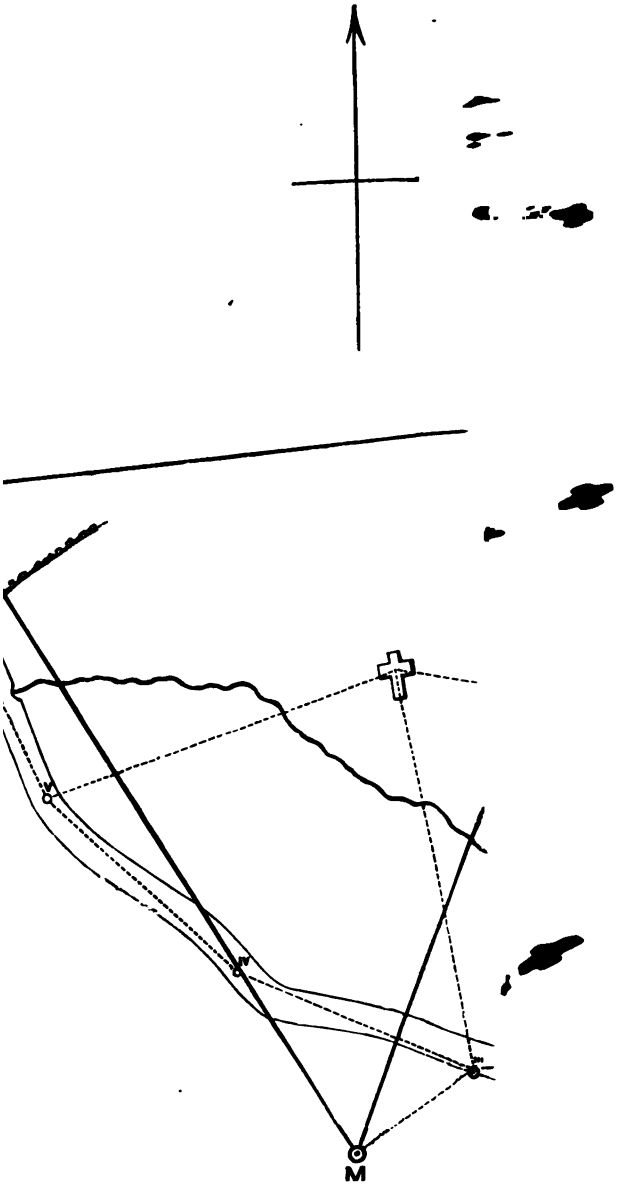
We must bear in mind that the chain column represents a line having no breadth, and therefore no representation of the sides of the road or any other detail must be made in it; if, in chaining, we cross a road or fence obliquely, it must not be represented in the Field Book as passing obliquely across the chain column, but must arrive at one side of the column and leave it at the other at points precisely opposite; as would be the case were the chain column of the thickness of a line, thus:—

Fig. 40.



All the figures entered refer either to linear measurements or

PLATE VI.



Scale 12 inches to a Mile.

The chain line is represented by a

heir direction; we must be careful, therefore, to distinguish ween these by attaching the signs of degrees and minutes the latter, so that they may not be mistaken for linear asurements. Some persons use a red pencil to enter the gles, and a black for the distances.

It is important that the entries should be clearly and legibly itten: if a mistake occurs, a line should be drawn through and a fresh entry made.

TRAVERSING.

Theoretically, the most accurate manner of using the eodolite for this purpose, is that in which we are altogether lependent of the magnetic needle. In this system, the ection of all the forward angles has reference to the angulation, and the side of the triangle to which they are erred is termed the "zero line," or directing line.

In illustration of this method, a page of a Field Book, and corresponding plan drawn to the scale of 12 inches to a le, are shown in Plate VI.

The different points at which the Theodolite has to be set in traversing to observe the forward angle, are prefixed in Field Book with the sign ⊙, and in describing the process traversing here, they will be alluded to by that sign.

In order to avoid confusion, the whole of the triangulation not shown, but only the Stations A, T, and M.

Having elected to commence the traversing at a convenient ation A, and selected the side A T as the "zero line": set the Theodolite exactly over that Station, adjusted to read rizontal angles (Page 37), and send an assistant to hold a le or flag at ⊙ I., where the road changes its direction.

Adjust the cross hairs of the Theodolite on T (zero line), lower clamping and micrometer screws, release the vernier

plate and bisect the foot of the pole at ⊙ I.; the angle recorded by the vernier on the horizontal circle is 251° 15′. This is entered in the chain column as the forward angle.

Perpendicular offsets are then measured with the chain (or wand used for the purpose), the sides of the road being distant 10 links on the left, and 98 on the right.

We then measure forwards in a direct line towards ⊙ I.,* at 150 links distance we are opposite the corner of an enclosure on the left, and take an offset to it 21 links.

At 270 links we measure an offset to the edge of the road (25 links) and to the angle in the enclosure (160 links), both on the left. Observe that, when offsets are measured to two or more objects on the same side, the measurements are all *inclusive*, not from one to another, but from the chain.

⊙ I. is 1250 links from the starting point, and we draw a line across the chain column at the end of this measurement.

Set up the Theodolite over ⊙ I., being careful not to disturb the relative positions of the vernier and horizontal plates. Adjust the cross hairs on A (lower clamping and micrometer screws), examine the vernier to make certain that it still remains recording the last forward angle 251° 15′, release the vernier plate, and direct the telescope first on the church steeple (15° 40′) then on the flag placed by the assistant at ⊙ II. (278° 10′). The position of this point he will have chosen as commanding the longest view down the road towards ⊙ III. Angles to points lying off the traversed line are observed first, the forward angle last.

We then chain forward to ⊙ II., taking such offsets as seem necessary (shown in the Field Book). At ⊙ II. we again set

* The accuracy of all the offset measurements depends on the preservation of the true line from ⊙ to ⊙ in chaining forward; this is a particular in which almost all beginners fail. It is the business of the chain follower to keep the line by observing either some intermediate or some distant mark which is exactly in the same line as the forward ⊙, and keep these two points dressed as he adjusts the chain.

up the Theodolite, release the lower clamping screw, and adjust the cross hairs on a flag left for the purpose at ⊙ I., ascertain that the vernier remains clamped at the last forward angle 278° 10′ (the same process as at ⊙ I.), direct the telescope on the forward angle (334° 5′).

A careful examination of the Field Book and the sketch simultaneously, will explain the method in which the remaining entries are made. At ⊙ III. and at ⊙ V. the church spire is again intersected; this system of intersecting important objects not more distant than half a mile or so from different ⊙s in traversing, will be found most useful; more especially when there are no regularly triangulated Stations. We not only thereby determine the position of such points, but also obtain a means of checking the accuracy of the work; for the angles taken from three or more ⊙s to the same point, will (if the work be correct) converge at that point on the plan.

The forward angle should be read alternately from the opposite verniers, commencing with that which was adjusted to zero at starting.

This is termed the "back angle system of traversing, in common with all other systems in which the direction of each forward angle is taken with reference to the back ⊙, and independent of the meridian.

Having commenced traversing from a triangulated Station A, we work up to and close on another Station as soon as possible, so as to test the work and throw out any error. We then enter in the Field Book "closed on M." The Theodolite may be left at ⊙ III., to which we then return, and observe the next forward angle with reference to ⊙ II. as before. If unable to close on a Station at the conclusion of a day's work, we should take an angle to a well defined distant point, and enter it in the Field Book as the "return angle"; on recommencing the work another day, the vernier is

adjusted to this angle, the Theodolite is set up exactly at the spot at which we left off, and the telescope again directed on the distant object.

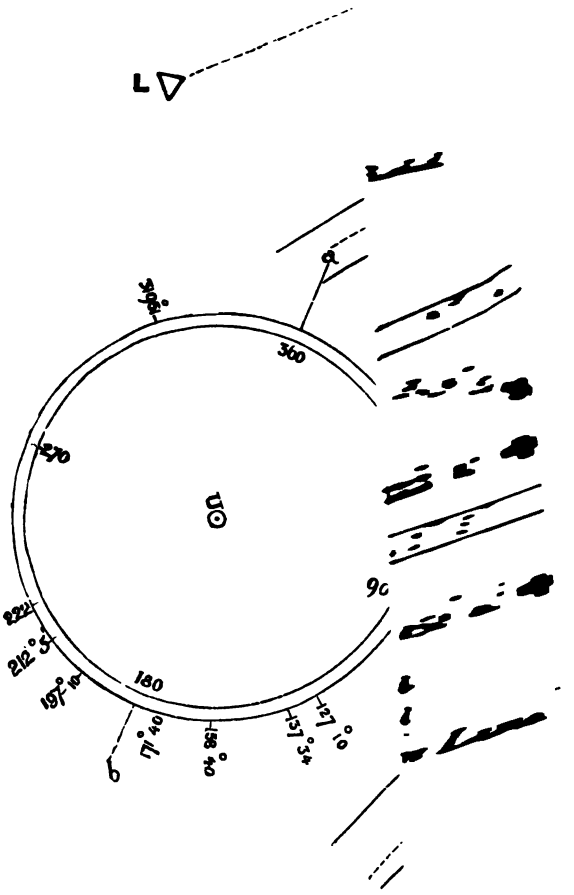
We should avail ourselves of every opportunity of checking the work by starting afresh from Stations as frequently as possible and working up to other Stations, by so doing we divide it into a series of separate operations, and confine any errors within narrow limits. If the work be incorrect in any part we at once detect the locality of the error when laying it down on the plan, and such error will not affect any part of the operation save that between the immediate starting and closing Stations.

MERIDIAN ZERO LINE.

The system just described is certainly the most correct when the accuracy of the triangulation can be thoroughly depended on; otherwise the adoption of the meridian as the zero line has many advantages, chief of which is that it is only necessary to set up the Theodolite at every alternate ⊙.

Referring to the example of traversing just described, we should on this system first set up the Theodolite at ⊙ I., instead of A, adjust it North and South for the observation of bearings (Page 40), and observe at once A 334° 30′ and ⊙ II. 181° 10′. The next place to set up the instrument would be ⊙ III., whence we can observe the bearing of ⊙ II. and ⊙ IV. at the same time. Next at ⊙ V, and so on.

It will be noticed that in taking the bearings of the back and forward ⊙s at the same time as at ⊙ I., the observed bearing of the back ⊙ A being 334° 30′, we know that 154° 30′, the opposite angle, would have been the bearing of the same line observed *at* A (Page 26, interpolation). To avoid confusion in plotting the work, therefore, it is better to record



Scale 30 inches to a Mil

the opposite angle for the bearing of the back ⊙, or set up the Theodolite with the vernier A always clamped to 360°, and read the bearing of the forward ⊙ from vernier A, and that of the back ⊙ from vernier B.

The linear measurements would be carried out in the same manner as in the back angle system.

Another common method of traversing is to set up the Theodolite at the starting point and observe the bearing of the *first* forward angle, applying afterwards the back angle system; so that, although using the meridian as the zero line, the possible error thereby introduced will affect only the meridianal direction of the whole piece of traversing between the starting and closing Station.

It will be found in practice that, when the magnetic meridian is adopted for the zero line, the former of these systems will produce quite as satisfactory results as the latter, and is peculiarly well adapted to traversing in winding lanes, which necessitate the frequent setting up of the Theodolite.

At every ⊙ a cross or other mark should be cut in the ground, in case it should be necessary to return there.

Offsets should not generally be taken to objects more than 50 yards or so distant from the chain line.

PLOTTING.

The process of laying down on the plan the work entered in the Field Book is termed "plotting."

It is merely a repetition on paper of the operations performed; the protractor representing the horizontal plate of the Theodolite, and the scale the chain.

We will suppose that the instruments provided are a circular cardboard protractor and the Marquois scales, the plotting to be performed from the accompanying extract from a Field Book. (Plate VII.)

The meridian being in this case the zero line, draw a line *a b* parallel to the meridian N S, in the part of the paper in which the work lies; adjust the protractor on this line 360° to the North, 180° South. Mark the point *c* at the centre.

Lay a weight on the protractor to prevent it from shifting, and dot off the position of as many angles as the circumference will contain without confusion, writing the degree at each. The protracter may then be removed.

The first angle in the Field Book is 42° 35′ to be laid off at the Station L. Lay the triangle to the marked degree and the centre *c*, and carry a line parallel to this to L. Measure off 410 links from the plan scale on this line, this gives the position of ⊙ I.

Again, lay the triangle to the next forward angle 127° 10′ and the point *c*, convey this to ⊙ I., measure off on it the total distance to the next ⊙ 525 links, without noticing at present any of the intermediate entries.

In the same manner plot from ⊙ to ⊙, and if the "closing angle" 38° 39′ pass exactly through Station R, and the distance 283 links likewise agrees, we have "closed" the plotting.

Return now to the offsets. Measure the forward distances as entered in the chain column from each ⊙, and lay off the corresponding offsets perpendicular to the forward angle. The position of the sides of the road being thus marked here and there, these points may be joined in the first place by straight lines, and afterwards drawn with the requisite amount of curve.

It must be borne in mind that the measurements both forward and offset are *inclusive*.

A plotting scale consisting of two or three hundred links, laid off from the scale on the edge of a card, will greatly facilitate these measurements.

The same course of plotting will be followed for laying down the work of either of the methods of traversing described.

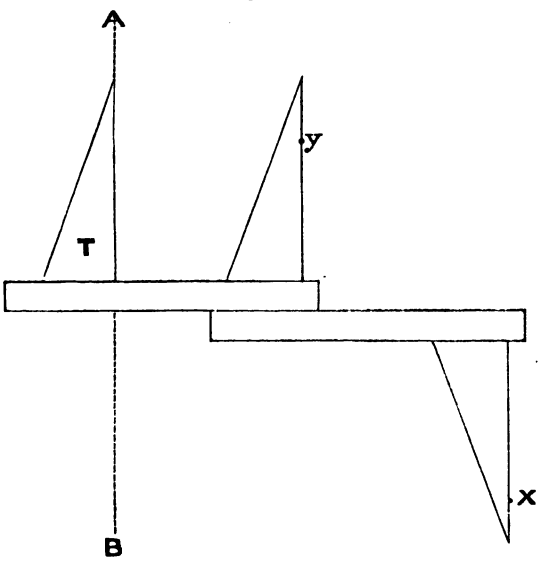
When the zero line is a side of one of the triangles, the protractor is of course adjusted on a line drawn parallel to it instead of a meridian.

The ⊙s are to be numbered corresponding with the Field Book. The forward angles are sometimes shown in colour to distinguish them, and the plan is finished up in Indian ink after having been correctly pencilled in.

Houses should be drawn with a mathematical pen and parallel rulers, not free hand. In drawing roads, draw the left side first.

Some difficulty will at first be found in carrying a line to a

Fig. 41.



considerable distance parallel to another on paper when using

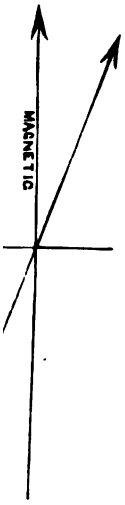
only the Marquois scales. The best way is to lay the fiducial edge of the triangle T to the given line A B, place the scale firmly against its base, the required parallel line may then be drawn through any point *y*, as in the figure. Or, by placing the two scales side by side and moving them alternately, a parallel line may be carried to any distance, or laid off at the other side through a point *x* if required.

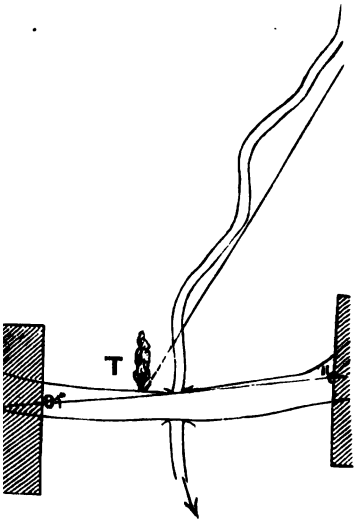
When the plotting is to be performed with the ivory protractor, either lay down all the angles at any convenient place on a line parallel to the zero line as just described; else cover the plan with lines parallel to the zero line about 3 inches apart, and with the triangle and scale slide the protractor itself up to the required point from one of these.

Or the plan, if small, may be executed on sketching paper, on which the meridians are printed so close together, that the ivory protractor may be laid parallel to them by eye.

The position of the plan should be shifted as required to enable the draughtsman to make the direction of the forward angle agree with that of the chain column of the Field Book laid upon it, else he would be apt to reverse the position of the offsets.

PLAT





Scale 30 inches t

SECTION XI.

SKETCHING ROADS, ETC.

The kind of sketching required usually for military purposes does not necessitate such a high degree of accuracy as the foregoing, the instruments being the prismatic compass and the ivory protractor, and the two processes of traversing and plotting being carried on in the field simultaneously; the most difficult part of sketching, viz., the representation of hills, must be reserved for after consideration.

If the reader has practised the method of traversing and plotting from the Field Book, he will find no difficulty in sketching at sight.

The sketching paper is prepared with parallel lines which may be used either as Meridians or as East and West lines as described. (Page 30).

This is held in a sketching case which is usually provided with a strap to pass round the surveyor's neck, whilst a loop fastened to one of his buttons, forms it into a sort of table. This, though apparently a convenient arrangement, must be condemned; as a beginner will certainly be unable to realize the relation of his sketch to the ground, unless he is able to hold it in a position corresponding with the latter. If he accustoms himself to do thus, it will greatly simplify the subject in every branch.

It may be well to explain, step by step, the manner in which a sketch of this nature was executed, though in doing so, much of what has been said has to be repeated.

The sketch being drawn on the scale of 30 inches to a mile, the scale of 6 inches to a mile engraved on the protractor was used, and each measurement multiplied by 5 (Page 6).

Commencing at ⊙ I., (Plate VIII.) we noticed a distant fir tree nearly in the continuation of the direction of the road giving a suitable point to march upon—observed the bearing 84°. Assumed a point on the sketch for the starting point ⊙ I., adjusted the protractor, its centre at this point, its edges parallel to the meridian lines and the graduated edge to the right; marked the position of 84° and drew a light line indefinitely in that direction.

Paced the width of the road (10 yards to the left) and dotted off that measurement perpendicular to the forward angle.

Returned to the starting point and looked out for some object, either intermediate or distant, on the same line as the fir-tree (Note, page 66), selected a bush in the hedge-row at *a*, and kept these two objects aligned whilst pacing forwards.

At 55 yards we reached the commencement of a stone bridge, the line of direction having brought us close to its left side. Marked this point on the sketch and paced the width of the bridge 8 yards, joined these points to the sides of the roads marked at the starting point.

Continued the forward measurement towards the fir-tree, recommencing the counting at 55. Sixty yards brought us to the far side of the bridge; at 80 yards we began to leave the left side of the road which was now 2 yards off. Noticing that the road continued of the same width 10 yards, we sketched in the remainder with regard to its position to the line of direction, without pacing more offsets.

At 105 yards we reached a cross road, at a spot whence we could command a good view down each road; halted here, and took the bearing of each 42° and 89°. The forward angle 42° was taken on a cottage chimney C, a stone on the road serving as an intermediate point of alignment.

Pacing forwards, the line of direction kept the middle of the road for 90 yards, so we sketched the sides in at 5 yards on each side.

Here a fresh forward angle had to be observed to a distant post P, 339°, laid off to the left, &c.

Wishing to sketch the stream from ⊙ IV., we observed the bearing of a poplar tree T, which seemed to be somewhat in the direction of its course 209° and paced on it, estimating here and there the distance of the stream as its position altered; this we were able to do with sufficient accuracy as the distance was at no part greater than 10 yards.

After following the stream for 180 yards we reached the side of the road near the starting place, and as this distance corresponded nearly with the measurement on the sketch, the correctness of the work was proved.

The forward angles should be drawn lightly, as they do not remain permanently on the sketch.

If the distance between the starting and closing Station be great, it may be well to check the work by interpolation (Page 26) occasionally; a check bearing to only one Station is even advantageous.

If a triangulation has been made, it should be used as much as possible. Start from a Station afresh whenever an opportunity occurs.

SECTION XII.

REPRESENTATION OF THE FEATURES OF THE GROUND.

The sketch being finished so far as to show the roads, fences, and other detail, we now come to the representation of the hills and undulations of the ground, which, in a tactical point of view, are of the utmost importance.

This part of military surveying gives the greatest scope for the display of individual intelligence and quickness.

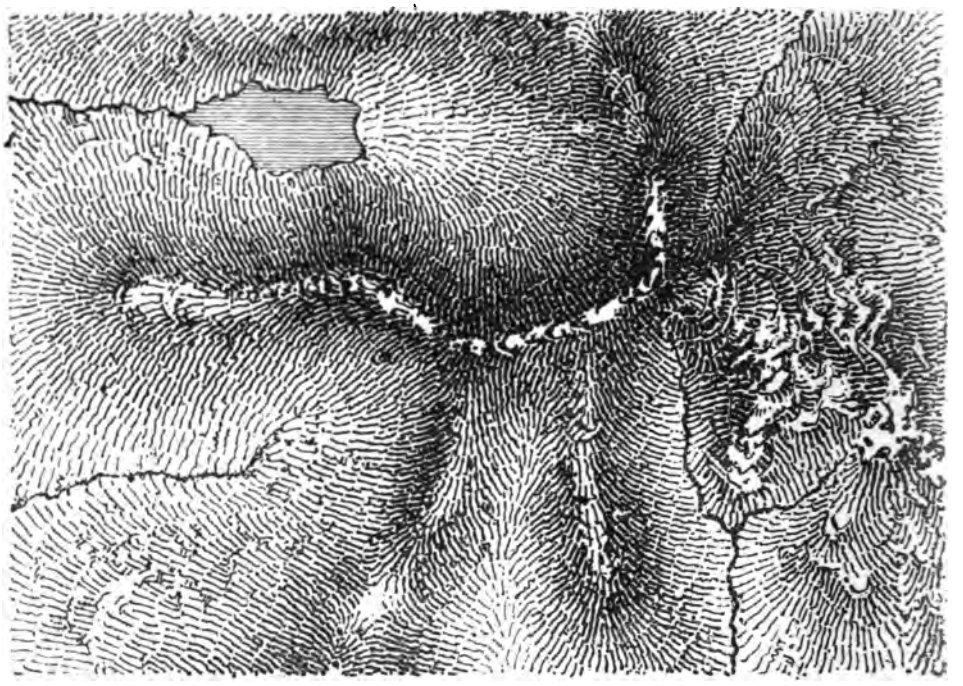
Hills must be represented in such a manner as to convey a striking and, at the same time, true and unexaggerated idea of the form of the various features, their slope or inclination to the horizon and their relative altitudes; in fact, there must be combined in the plan the information which would be conveyed both by a vertical and a horizontal view of the ground.

These conditions being unnatural, a conventional style of delineation has to be adopted.

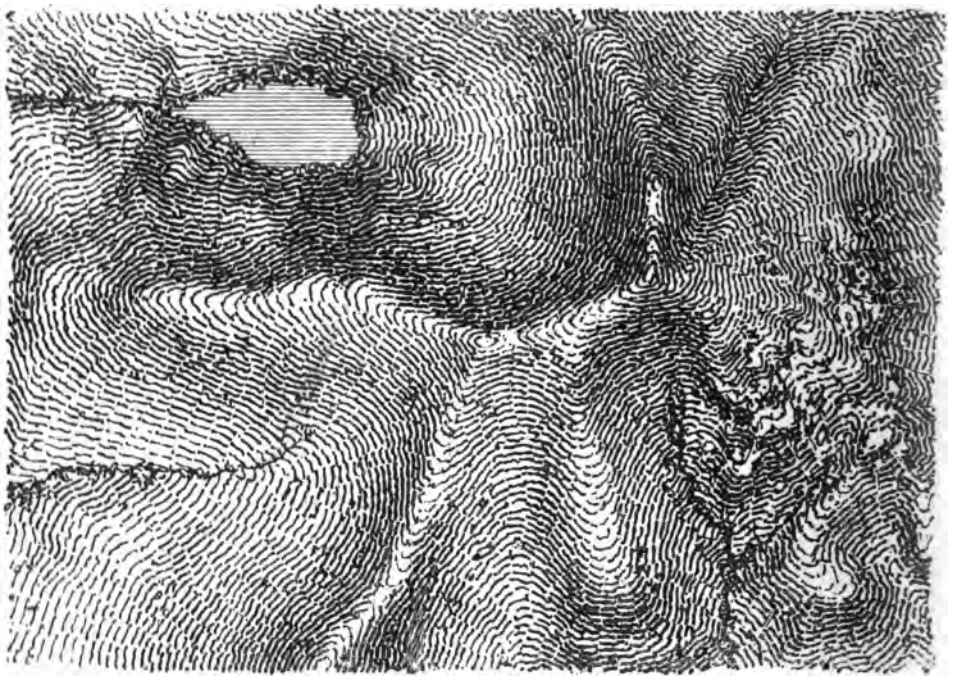
The earliest manner of representing hills seems to have been by a sort of bird's-eye view. This style undoubtedly has the advantage of appealing, in an unequalled degree, to the understanding of persons uneducated to read military plans, and as such, is still to some extent adopted in the "maps of the seat of war" published for the million. It is, however, quite insufficient for the requirements of a military sketch, as it merely conveys the idea of the existence of a hill in a certain locality, without defining its entire form, only the near side of the hills being visible.

Later on, hills were depicted as occupying their proper area

PLATE IX. To face p. 79



Vertical Style of Drawing.



Horizontal Style of Drawing.

on the map, the idea of relief being obtained on the supposition that the observer viewed them from a point vertically over every point on the ground; so that the eminences would appear distinct and well defined, whilst the valleys and low ground would be affected by atmospheric perspective, and would be subdued and blended. Thus, the body of shade and the high light was distributed about the summits, and the valleys were kept dim and faint.

This system gives a capital effect of relief to the sketch, and enables us to show the relative altitudes fairly. On the other hand, it conveys an entirely false idea of the form of the slopes, which appear uniformly concave, it is also ill adapted for military sketches as showing least distinctly the most important tactical features, the low ground and manœuvring slopes, under 15° or so.

For the effectual representation of some kinds of ground (particularly mountains), it is difficult to dispense altogether with a modification of this arrangement of shade.

In the example, the vertical style of drawing is represented, wherein every touch or hâchure is drawn orthogonally to the contours, or in the direction of the fall of the ground.

The same distribution of shade might be made on the horizontal system, in which each hâchure coincides with the contour.

Excellent effects of relief are produced in brushwork with little labour, but to execute this system of hill shading requires considerable practice with the brush; it is best suited to the sketches that accompany the reconnaissances of positions, roads, and rivers.

The effect produced by the Anaglyptograph process on the principle of oblique illumination is very striking, good specimens of this style may be seen in Siborne's maps of the battle fields of 1815.

In the present system a definite amount of shade is allotted

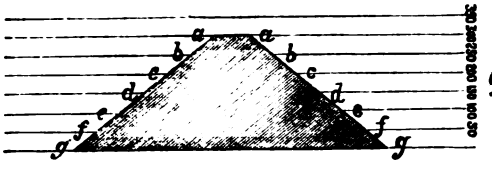
to certain slopes without reference to their relative altitudes, these being shown either by figures or by the *contours*.

A contour is the line of intersection of a hill by a horizontal plane.

For example, the line defined by the edge of the sea is a contour, and on a coast where the tide rises and falls 30 feet, seven contours might be marked at 5 feet vertical intervals, by tracing this line at every 5 feet difference of level of the tide. These lines, surveyed and drawn to scale, would be a *contour plan* of that ground.

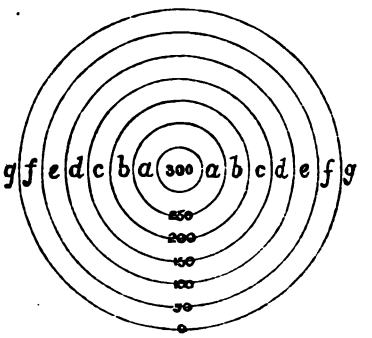
Suppose a hill to be of the form of a truncated cone

Fig. 42.



Elevation.

Fig. 43.



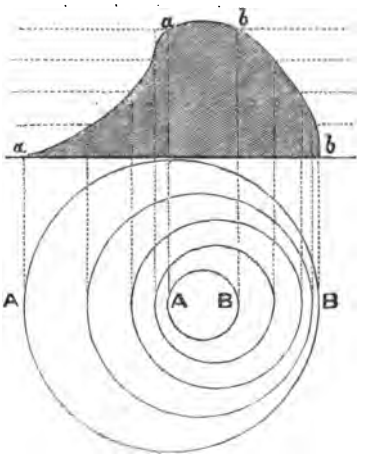
Plan.

(Fig. 42), and the vertical distance between the horizontal planes *a*, *b*, *c*, &c., by which it is intersected to be 50 feet, the contour plan of the same (Fig. 43) will show the height of the hill 300 feet, or the altitude of any part of it.

Besides the relative altitudes, the contours explain the form and flexure of every slope. A A and B B (Fig. 44) show the exact concavity and convexity of the slopes *a a* and *b b*, as the contours will occur in smaller horizontal distances in proportion to the steepness of the ground.

As all military sketching is now based on the contour

Fig. 44.



system, the beginner will probably contour a small piece of hilly ground instrumentally, preparatory to sketching.

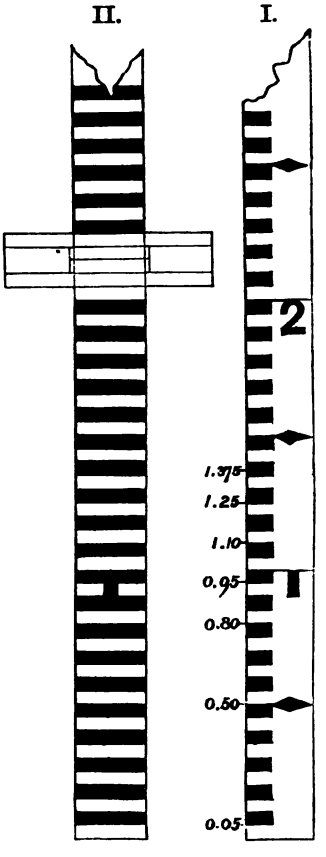
SECTION XIII.

CONTOURING.

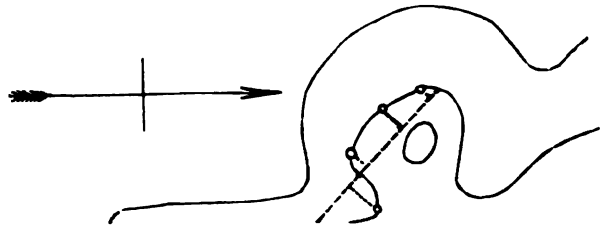
The instruments used for this purpose will be a spirit level (described in the Section on levelling), or the Theodolite, which will answer as well for small operations, and a levelling staff.

There are several patterns of levelling staff; that most in use is 14 feet in length, in three joints, closing up telescopically for convenience of carriage. Its face is white, and is divided into feet and decimals in black lines (I.), this is the best sort for ordinary levelling operations. The better sort for contouring is that with a vane (II.), which may be raised or lowered by an assistant, until the cross wire fixed across a square hole at its centre corresponds with any required height on the staff. It is preferred on account of the vane being visible at long distances, at which the figures and lines on the staff (I.) would be quite invisible through the telescope.

Fig. 45.



The staff I. (being the more common) will be that supposed to be used in this description.



If the sea or a lake bounds the feature to be contoured, the contours should be measured upwards from it; but usually it will be better to commence at the top of the hill and measure the vertical distances downwards.

The first object will be to plant pickets in the hill side at points each the required vertical interval of the contours apart. It will be found convenient to set these pickets in a line, this may be called the "initial line," and the points so fixed "initial points."

We will suppose that the ground is to be surveyed with contours at the vertical interval of 12·5 feet.

Having selected a line *a i* as the "initial line" and observed its bearing, we plant a picket at *a* the top of the hill, Plate X.

One of the party holds the levelling staff perpendicularly at *a*, the Theodolite or spirit level is set up at any place X so far down the hill that the telescope may, when levelled, bear on the lower part of the staff. It is found to intersect the figure 1·23 feet by the cross hairs.

A difference of level of 12·5 feet being required; the staff must now be moved down hill on the initial line until the cross hairs intersect 13·73 (that is, 12·5 + 1·23); when this level is found, a picket is driven in at the spot.

The staff remains here while the Theodolite is taken to a point Y, so far below *b*, that the telescope, when levelled, may cut the lower part of the staff, as before. The figure is read, say 0·94.

Then, to find the position of the next initial point, the staff must be moved down hill until 0·94 + 12·5 = 13·44 is cut by the cross hairs, this point is 25 feet below the upper contour.

This operation is repeated until the foot of the hill *d* is reached.

If the required vertical interval between the contours is greater than can be measured by the staff at once, say 25 feet,

it will be well to keep a register of the back and forward readings of the levelling staff, to guard against error. Thus:

Back.	Forward.	Difference.
1·15	13·77	12·62
·52	12·9	12·38
		25·
2·64	13·51	10·87
1·98	13·69	11·71
2·83	5·25	2·42
		25·

If the vertical intervals are to be measured *upwards* commencing from *d*, the Theodolite must be placed so far *above* that point that the telescope shall be on a level with the upper part of the staff held there, read the height and send the levelling staff up the initial line till the difference between the back and forward readings is equal to the required vertical interval.

The initial points being planted, their position is now found by measuring with chain or tape from *a*, *b* is 105 yards, *c* 230 yards, *d* 276. If the ground be steep the deductions given (Page 18) must be made, to reduce these measurements to their horizontal length.

The levelling of the first contour is now undertaken. Set up and level the Theodolite at any point T where a good view of the ground on which the contour will lie may be obtained; placing it at such a level that the telescope will intersect *some part* of the levelling staff held at *a*.

The figure being read 10·4, this is noted down. The assistant now takes the staff to the points 1, 2, 3, 4, &c., at each of these we motion him up or down hill until the same height 10·4 is intersected by the cross hairs, a picket is planted at each of these points when found.

The choice of position for these pickets must be regulated by the form of the curve of the contour—in this matter the person carrying the staff must exercise some judgment. They will usually be placed at the extremes of the inward and outward curve as being the points which will define its form best.

When it becomes necessary to shift the position of the Theodolite in order to keep the staff in view, as, for instance, if unable to observe the staff beyond 7 on contour *a*, we transfer the Theodolite to any commanding point of view O about the same level, level it and read the staff held at 7. Note down this figure and continue the contour by beckoning the staff bearer up or down hill until the cross hairs again intersect this figure.

All necessary movements should be communicated from the observer at the Theodolite to the staff bearer by signal, not by words.

It is easy to level the contour on steep ground, but the difficulty of finding its true position increases as the ground becomes more level. A great deal depends on the judgment of the staff bearer who must be careful to trace the contour round all the minor features.

The surveying of the pickets marking the contour is a matter requiring some management, to prevent it from being a very lengthy operation.

In this, as in surveying all irregular lines, keep to the rule of long lines of direction, with offsets to the various pickets.

Thus, contour *a* may be surveyed by observing with

Theodolite or compass the bearing of the two lines *a e*, *a f*, and would be entered in the Field Book, thus:—

	132	2
35	55	
	14	7
	4 30′	
Again, at *a*		
3	170	
22	123	
77	79	
19	27	
	313° 10′	

At Initial point *a*, measurements in yards.

Part of contour *c* would be entered thus:—

9	162	
22	110	
16	92	
	70	28
	310°	
	(137)	
22	128	
15	111	
17	77	
	267°	
	(136)	
21	88	
14	40	
	315°	

At Initial point *c*, measurements in yards.

When the contour picket occurs *on* the forward angle, surround the entry by a circle, (as shown in chain column), so as to distinguish it.

If the contour survey is of any great extent, two or three Initial lines should be laid down, and the Initial points picketed on them, starting from a common level carefully obtained.

These points serve in the vertical plane the same purpose

that Stations of the Triangulation do in the horizontal; we commence levelling a contour from one Initial point and can estimate its accuracy by the proximity with which it arrives at the same level on another Initial line.

A sketch of the contours should be made in the field at any convenient scale, as a check on the general accuracy of the work; for an error, unless immediately detected, would entail great trouble.

It is advisable to level and mark out only so much as there will be time to survey on the same day.

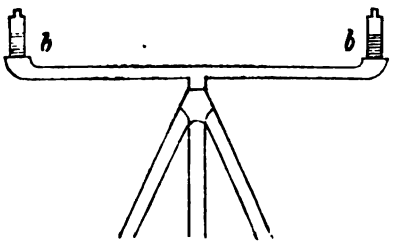
SECTION XIV.

SIMPLER METHODS OF CONTOURING.

If the spirit level, Theodolite, or levelling staff are not provided, contours can be laid down with sufficient accuracy for most purposes by simpler and more portable instruments.

There are a great number of designs for levels; of these, the water level is easily constructed on emergency. The bottoms are cut off two small bottles *b b*, and these are connected and communication established between them by a metal tube, in the ends of which they are set by putty or plaster of Paris, (a piece of gas pipe or a musket barrel will answer the purpose).

Fig. 46.



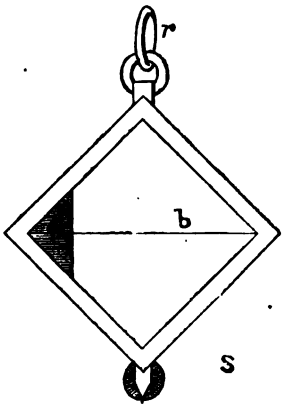
This is mounted on a tripod stand.

Sufficient water being poured in to fill the bottles half full, the two surfaces will necessarily be at the same level; so that the observer, standing a few feet off, can observe the horizontal plane by bringing his eye to the level of the two surfaces. The bottles should be corked when the instrument is carried, and uncorked when used for an observation.

It is a very cumbrous and inconvenient instrument.

The reflecting level is very portable, it consists of a piece of mirror about an inch square, set in a metal frame; it is held at arm's length by the ring *r*. The reflexion of the observer's eye in the mirror is on the same level as any object seen through the unsilvered portion *a* in coincidence with a fine wire *b*. The screw *s* shifts the centre of gravity so as to adjust the vertical position of the mirror when suspended.

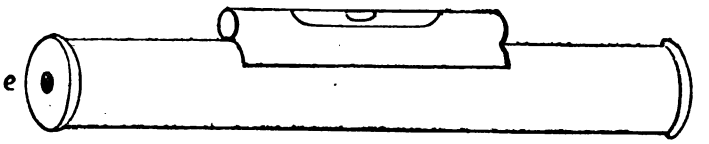
Fig. 47.



There are many other varieties of portable levels which it would be needless to describe here, none is more useful than the hand spirit level with which all the levelling operations connected with military surveying may be performed with considerable accuracy.

A small spirit level is attached to a metal tube about 4 inches in length.

Fig. 48.



The bubble is reflected to the eye-piece through an opening in the tube, when level, by an oblique mirror in the interior. To use it, look through the eye-piece *e;* any object seen in coincidence with the bubble and a cross score inside, is on the same level as the observer's eye. A little difficulty will be at first experienced in retaining the reflexion of the bubble for more than a second, but after a little practice this difficulty will be overcome.

The object end of the tube is closed by a piece of common glass to exclude dirt.

The system of contouring detailed above may be carried out with this hand spirit level, and any pole instead of a levelling staff; on this, feet and 10ths should be marked, and a conspicuous mark, such as a piece of paper, attached to it at any height.

To find the position of the Initial points. Fasten the mark low on the pole, say 1·5—let this be held at the Initial point. The observer moves down hill till the spirit level shows that his eye is level with the mark. If it be required to find a vertical interval of 10·5 feet, the assistant shifts the mark to the figure $10{\cdot}5 + 1{\cdot}5 = 12{\cdot}0$, and carries the pole down hill on the Initial line until the spirit level intersects the mark, the observer being careful, meanwhile, not to move from his position.

In tracing the contour, the assistant holds the pole upright at *c* (Plate X.), with the mark fastened at any part of it. The observer stations himself with the hand level at any convenient point for observation H within about 200 yards, and moves up or down hill until his eye is on a level with the mark; remaining here, he can direct the assistant in laying out the contour by motioning him up or down hill until the spirit level intersects the mark, he can thus lay out the contour for 200 or 300 yards on each side without moving, and there should not be a vertical error of more than a foot in any picket at that distance, an error which, in tolerably steep ground, will not displace the contour in any appreciable degree when drawn to scale on paper.

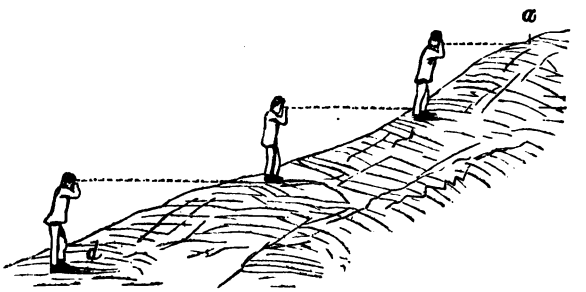
The process of contouring may even be performed without assistants by one person. In this case he should stick a rod in the ground at the Initial point of the contour, and fasten a conspicuous mark on it at the height of his eye. He can then place himself at the level of this point as long as it is in

sight by moving up or down, till the bubble of the spirit level coincides with it, and can mark out the contour by twigs or pieces of paper. If he has good eye-sight and a steady hand he may perform this operation with considerable accuracy and with greater rapidity than with the Theodolite and levelling staff.

The chief difficulty in contouring single handed is to find the position of the Initial points. This may be done by employing the height of the eye from the ground as the vertical measure. Persons of average height can easily learn a position in which the height of the eye is just 5 feet. If this is uncertain, pass the spirit level through a ring at one end of a line, the other end of which is attached to a flat piece of wood to be placed under the foot, so arranged as to give the level a height of 5 feet.

If the measurements can be taken on a road or other

Fig. 49.



smooth surface, the surveyor may measure them as shown in the figure, leaving a stone or other mark at each point, from which to measure the next. Thus *d* is 3 vertical intervals of 5 feet, or 15 feet below *a*. In the same way, the vertical measurements may be made upwards on a smooth surface, by noticing the spot where the level visual ray strikes the surface of the ground.

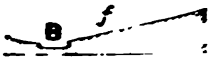
If the ground is covered with heath or any vegetation, other means must be resorted to.

The position of the Initial points being found, the surveyor should stand at each and try all round for objects at the height of his eye; their distance is immaterial. These he should note down, with the level they represent.

Then, when surveying a large tract of ground, he can find his level by observing any of these objects that may be visible when he cannot see the Initial points.

The points by which the contour is marked out may be surveyed with the compass. Starting from the Initial point and observing the bearing of some object in the general direction of the contour, perpendicular offsets being taken to the various marks.

None of these methods of contouring could be attempted in sketching ground, being much too tedious. They would only be performed for educational purposes, or when a very accurate survey of a position is required for such purposes as constructing fortifications, laying out canals, railways, or roads, &c.



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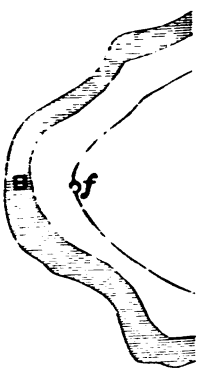

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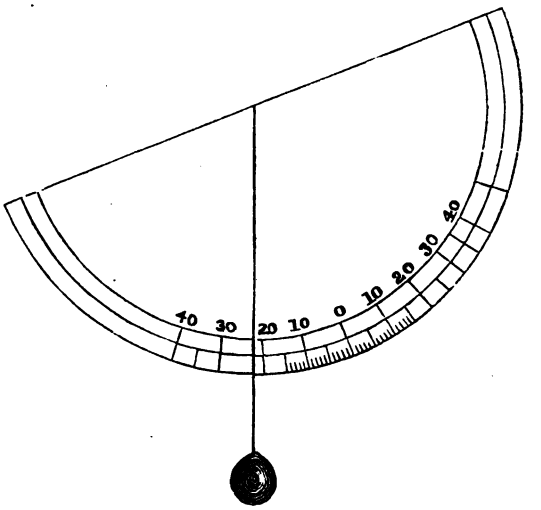
SECTION XV.

THE CLINOMETER.—METHOD OF CONDUCTING A MILITARY HILL SKETCH.

This little instrument may be made on a quadrant or a semicircle of stout cardboard (about twice the size of the figure), its edge being graduated from a centre, from which a plummet is hung.

Fig. 50.

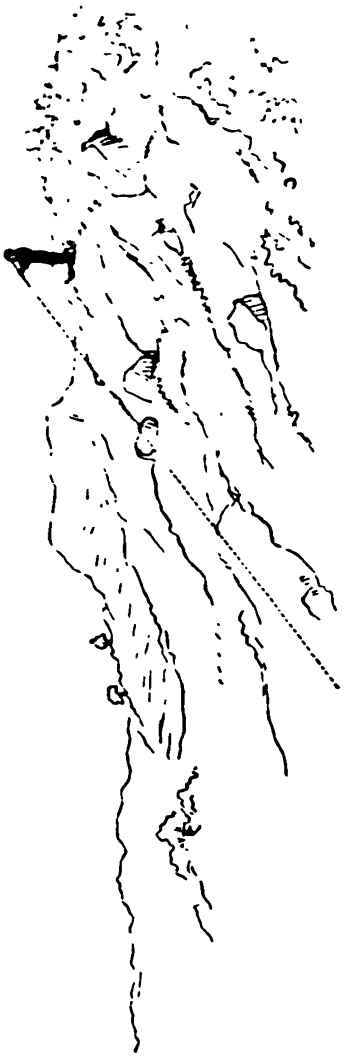


The zero is placed perpendicular to the diameter, so that when the clinometer is held with the plumb line coinciding with O a level line can be observed by looking along the edge.

To observe the slope or declination from the horizontal plane. The clinometer is held with both hands at some distance from the eye, with the diameter parallel to the surface of the ground, when the plumb line indicates the elevation or depression in degrees.

The contours of the ground may be sketched to some extent mechanically with the clinometer, and more rapidly than in the foregoing methods, though with less approach to the mathematical accuracy that belongs to a contour survey.

Fig. 51.



If the slope of the hill *a* B Plate XI. (I.) be observed 2° we can calculate in what horizontal distance any required vertical interval (or difference of level) will occur.

Let the vertical interval be 18 feet 9 inches. Then we have a right angled triangle *a b c* Plate XI. (I.) of which one of the angles $a = 2°$, and the side $b c = 18{\cdot}75$ are given: to find $a c$ the cotangent. This is 179 yards.

Then if the slope continue constant at 2° as far as an object which has been laid down on the sketch, for instance a stream B; the position of as many contours at 179 yards apart as the distance between *a* and B will contain, may be marked *b*, *d*, *e*, *f*, Plate XI. (II.), and each of these points will represent a vertical interval of 18·75 feet.

If from the same point *a* the slope in the direction of C, Plate XI. (II.) be observed to be uniformly 4°, the horizontal distance in which 18·75 feet vertical will occur, will be 89 yards; and as many repetitions of this distance as *a* C,

Plate XI. (II.) will contain, may be marked off on the sketch, viz., b', d', e', f'

In the same manner, if the slope towards D be observed 8°, the horizontal distance between the contours will be 45 yards.

The contours may then be joined through the points as shown, Plate XI. (II.) according to the form of the ground.

The calculations mentioned are of course not carried out in the field, all this is prepared beforehand.

For this purpose a table of cotangents is first prepared, showing the horizontal equivalents for the given vertical interval at each degree of slope up to about 30°. This table may be written on the clinometer for easy reference.

The cotangent or horizontal equivalent for 1 foot at 1° slope is 19·0966 yards—from this a table of horizontal equivalents for any required vertical interval may be easily prepared.

If, for instance, the required vertical interval be 25 feet, the horizontal equivalent at 1° is $19{\cdot}0966 \times 25 = 477{\cdot}4$ yds.

Then, at 2°, $\frac{477{\cdot}4}{2} = 239$ yards.

3°, $\frac{477{\cdot}4}{3} = 159$ yards, &c.

Next, in order to save the trouble of laying off these distances to scale on the sketch with the protractor, lay down on the edges of a card two or three horizontal equivalents for each degree of slope, to scale.

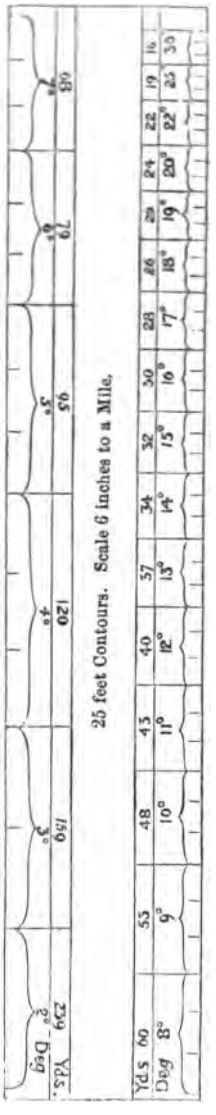
If, for instance, the scale be 6 inches to a mile and the vertical interval 25 feet, a scale of horizontal equivalents may be constructed in this form.*

In field sketching this may be advantageously substituted for the protractor, as, by applying it to the sketch, one or more horizontal equivalents for the observed slope may be at once marked off.

* This may be made of the same shape as the protractor and glued on the back, or if the clinometer be made of rectangular form a similar scale may be pasted on the back.

These conditions of 25 ft. contours, scale 6 inches to a mile, are those on which the horizontal equivalents are laid down on the outer edge of the scale of shade in use at present. They produce a scale well adapted for expressing ordinary ground.

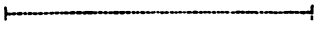
Fig. 52.



As, however, the horizontal equivalents are only given for a few slopes, 2°, 3°, 5°, 10°, 15°, 20°, 25°, 30°, these are not sufficient for field sketching, though suitable for shading the contours.*

The same scale of horizontal equivalents may be used for sketching at *any scale*, but the vertical intervals which they will represent will vary in proportion, for instance, the horizontal equivalent for 25 feet at 1° slope is as has been shown 477·4 yards, this drawn to the scale of 6 inches to a mile is of this length.

Fig. 53.



Now, if the plan scale were 12 inches to a mile, this length in plan will represent only $\frac{1}{2}$ or 238·6 yards.

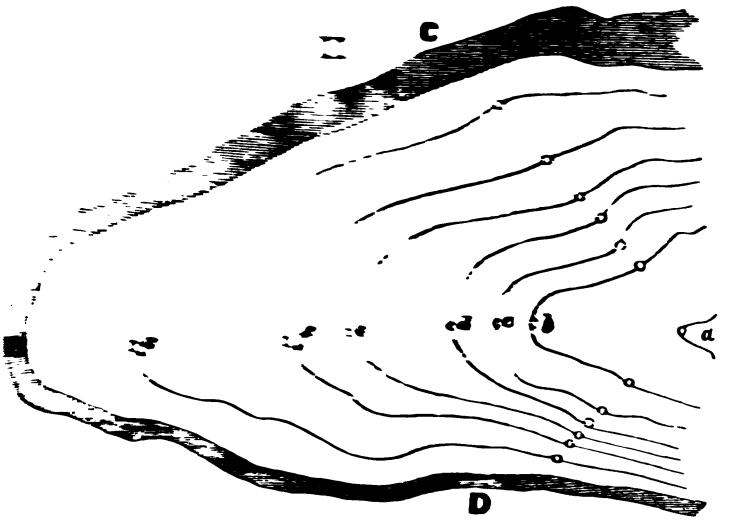
Similarly, the horizontal equivalent for 2°, which on the scale of 6 inches to a mile measures 238·6 yards, will measure on 12 inches to a mile one half or 119·3 yards, 3° will be 80 yards, &c.

Likewise, the vertical interval represented by the same horizontal equivalents will vary in like

* The horizontal equivalents on the scale of shade used at Woolwich are for 50 feet contours, and consequently twice the lengths of those in the figure.

To face p. 99.

Section on a E. magnetic meridian of Fig. 1.



Scale 12 inches to a Mile. Contours 12·5 feet.

proportion; the vertical interval at 12 inches to a mile will be half that represented by the same distance on the sketch at 6 inches to a mile, viz., 12·5 feet.

The vertical interval which these horizontal equivalents will represent at scales other than 6 inches to a mile may be found by proportion. Thus, if the scale be 9 inches to a mile

$$9 : 6 : : 25 = 16{\cdot}66 \text{ feet.}$$

Now, if it were usual for the slope of hills to continue constant for a considerable distance as in Plate XI. (I.), the process of contouring as described would be very simple. But as the slopes as a rule vary constantly, they must be subdivided in such a manner that the horizontal equivalents may be distributed in the order expressing the varying form of the slope.

For example. The scale in this instance being 12 inches to a mile, the horizontal equivalents will represent half the vertical interval which they represent at the scale of 6 inches to a mile (12·5 feet), and their length will also be in each case half that which they express as calculated for that scale, viz.,

yds.	yds.	yds.	yds.	yds.	yds.
2° = 119	6° = 40	10° = 24	14° = 17	18° = 13	24° = 10
3° = 80	7° = 34	11° = 22	15° = 16	19° = 12	26° = 9
4° = 60	8° = 30	12° = 20	16° = 15	20° = 12	28° = 8
5° = 48	9° = 26	13° = 18	17° = 14	22° = 11	30° = 8

Standing at *a*, Plate XII. (I.) the slope is observed to be 2° for some distance; mark off from the scale of horizontal equivalents that for 2° in the direction of B, and pace the corresponding distance 119 yards to *b*; this places us at the spot on the ground agreeing with that marked on the sketch.*

* It will be remarked that the horizontal equivalent laid down in the sketch is the base, whereas we pace the corresponding distance on the Hypothenuse or surface of the ground. The difference between the hypo. and base, however, is so trifling at low gradients that we may ignore it when the measurements are made by pacing. At so steep a slope as 15° the difference would be only 3½ yds. in every hundred, at 10° it would be only 1½ yds.

Here the slope is again observed and found to be 8°; pacing forward we find that this continues far enough to admit two contours, each 30 yards (the horizontal equivalent at 8°).

At *d* the slope is 3°, we lay down and pace 80 yards. At *e* the slope is 5°, distance 48 yards.

From *f* the slope continues 2° as far as the stream, and we find that the distance on the sketch will only contain one horizontal equivalent.

In the same manner we distribute the contours towards C in the horizontal equivalents successively for the observed slopes 4°, 10°, 10°, 12°, 6°, 4°.

And from *a* towards D for 4°, 7°, 15°, 20°, 20°, 20°, giving points on the same levels and same contours as *b*, *c*, *d*, *e*, *f*, *g*.

The difficulty of placing the contours increases in undulating ground, Plate XIII.

Here, commencing at A we find the first part of the slope to be 7°, lay off the horizontal equivalent and pace 68 yards to *b*.

From hence the slope is observed to be 12° for a considerable distance, pacing towards B we find that it continues sufficiently far to contain three horizontal equivalents, each 40 yards, *c*, *d*, *e*.

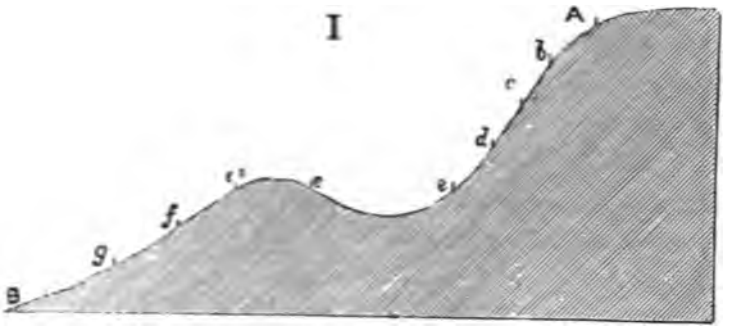
At *e*, judging that we have reached about the same level as the knoll, we use the clinometer as a level, looking along the edge whilst the plumb line agrees with O. Making due allowance for the height of the eye from the ground, we find that the level at which we are standing strikes the knoll at *e'*. Judging that the dip between *e* and *e'* will not include another contour we pace across 180 yards to this spot and mark that distance *e'* on the sketch.

Here we notice that the slope is nearly uniform for a distance that we judge to be about 200 yards on each side, towards C and D. The observed slope towards C being 9°, we mark off on the sketch as many repetitions of 53 yards as

PLATE XIII.

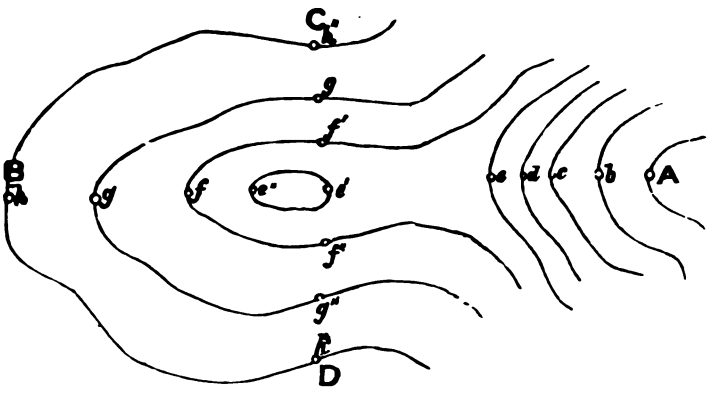
To face p. 103.

I



Section on A B, heights to distances 6 to 1.

II



Scale 12 inches to a Mile. Contours 12·5 feet.

will fit in that distance, viz., f', g', h'. And towards D the horizontal equivalents for 7° fixing f'', g'', h''.

We now pace to e'', a point which we judge to be on the same level as e' distant 93 yards, and lay down this point on the sketch.

Starting afresh from here, we fix f, g, h, successively at the distances due to 7°, 5°, and 4°, and join in the contours with a due regard to the form of the ground intervening between them and the points already fixed on the same contours.

It would be impossible here to explain precise methods of obtaining the contours in every formation of ground; fresh difficulties will occur in each, which experience and judgment alone will enable the learner to overcome. He must endeavour early to learn to estimate the distance in which the vertical interval of the contours will occur at various slopes; otherwise he will be puzzled as to *what part* of a convex or concave slope he is to observe with the clinometer.

An isolated feature may be contoured with some accuracy with the clinometer, but in some districts a difficulty will occur in finding a natural level common to the whole sketch, from which to commence the observation of the gradients, so that the contours of the features thus separately surveyed may be joined to each other with truth. The necessity for this will be greater in proportion to the greatness of the vertical interval.

If the sketch includes a coast line, a lake, or a sluggish river, we may avail ourselves of these as natural levels, and work upwards from them.

In some formations as in the Bagshot district the high ground consists of a series of level plateaux with well defined crest lines which furnish a natural level from which we may work downwards.

A description of the manner in which a contour sketch would be performed in this district will be now given, Plate XIV.

After having laid down the triangulation as shown, the roads, canal, &c., were traversed, starting from and closing on the Stations frequently.

Next, the crest of the plateau was traversed in the manner recommended for the surveying of all irregular lines (long forward angles and perpendicular offsets). Thus, starting at C we took the bearing of a conspicuous tree for direction and traversed to *a*, judging or pacing the distance of the crest as we advanced. At *a* we took the bearing of an object in the general direction of the crest, and traversed up to *b*, sketching as we went. At *b* we took the forward angle on B, traversed up to and *closed* on it. Here we started afresh and worked round the crest until we closed on D, &c.

Regarding this crest line as the upper contour of the ground and a common level, we commenced the observation of the lower contours from it. Thus, at *f* we found that Station F gave a suitable line of direction, and we observed the successive slopes in that direction and laid down the corresponding horizontal equivalents for 11°, 10°, and 6°.* Next at *h*, we observed a suitable line of direction with the compass, and noticing that the slope continued uniform at 12° for a distance which we judged to be 300 yards we were enabled to mark off at once the position of as many contours as that distance would contain at 60 yards apart. We now joined these to the contours previously surveyed from *f*, having regard to the form of the intervening ground.

* The scale being 4 inches to a mile the horizontal equivalents will represent a vertical interval of $\frac{25 \times 6}{4} = 37{\cdot}5$ feet (Page 99), and the actual lengths of the horizontal equivalents will be

for 1°. $19{\cdot}0966 \times 37{\cdot}5 = 716$ yards (Page 95).

$2° = \frac{716}{2} = 358$ yards.

$3° = \frac{716}{3} = 235$ yards, &c.

Bangalore Canal
Bombay Road
203
203 21.2.3

All the section lines (as they may be termed) on which we worked are shown dotted in the diagram, and it will be noticed that whenever an opportunity occurred they were taken towards some object, the position of which was known on the sketch so as to avoid the necessity of observing a line of direction with the compass.

It will be noticed that these section lines coincide nearly with the watershed line of each under feature. The exact watershed would be followed, were it not for the inconvenience of continually observing a fresh line of direction. By a little judgment a straight line may generally be observed, which will follow it sufficiently closely to enable us to trace the position of the contours through this part of the underfeatures where the contortions always occur.

The watercourses may be joined in by eye, as they have little character, being worn smooth by the action of water, and all irregularities filled in by the soil, &c., washed from the watersheds in the course of ages.

The accuracy of the crest of the plateau as a true level may be objected to as conjectural; we know by experience, however, that it is at least *as* certain as would be any line levelled by the clinometer. If provided with the hand spirit level (Page 89), the surveyor need not be dependant on the crest or any natural level existing on the ground, but may always place himself by its aid at the same level as the point at which he commenced.

After having worked down a section line to the foot of a hill, it might seem advisable to start from the lowest contour reached and work upwards in the same manner in a fresh direction to the crest again. In some cases this may be done, but the uncertainty of the whole system causes errors to accumulate so rapidly that we should seldom regain the crest at nearly the expected level on this system.

There will probably be many minor features of the ground

which will not be shown by the contours; these should be indicated by a little sketching as a guide for correct shading.

By means of the clinometer we may ascertain the approximate elevation or depression of any points in the sketch the position of which is known—and when time will not admit of a regular method of contouring being carried out, such information will give the sketch nearly as great value.

Thus, supposing Bisworth Plain to have been only roughly sketched, the roads, &c., and the crest, only being completed. Standing at C, the angle of depression of K being carefully observed with the clinometer would be found 5°, and on applying the scale of horizontal equivalents to the line C K we find that it will contain six contours, whence K is $37{\cdot}5 \times 6 =$ 225 feet below C. Again, the angle of depression of F from B being found 4°, and three horizontal equivalents for this slope being contained in the distance on the sketch gives F a difference of level of $37{\cdot}5 \times 3 = 112{\cdot}5$ feet below B. Several points being determined in this manner, their height in feet may be marked on them in the sketch, either above or below the point of observation (or datum point).

After considerable practice in contouring and general sketching, one may obtain such an appreciation of slopes and knowledge of the horizontal position of the contours both in plan and on the ground as to be able to sketch the ground in contours without any instrument, within 5 to 10 per cent. of truth.

An experienced surveyor will also combine the operations of planimetry and hill sketching, so that he need not visit the same spot twice.

SKETC

SECTION XVI.

SKETCHING WITHOUT INSTRUMENTS.

If an officer is called upon to produce a sketch of a position on active service, when he will probably be unprovided with instruments, he can do so with considerable accuracy at the cost of a little more trouble and judgment.

The kind of surveying about to be described is so simple that it would seem to be that which a beginner should first learn, but it will be found that in order to produce a sketch of any value the officer must first practice accurate and detailed surveying.

All that is required is a straight edged piece of wood, a scale of yards, and the back of a book or a sheet of paper fastened on a board, to draw upon.

To traverse a road. Draw a line in any convenient direction to represent the middle of the road. Lay the sketch on the ground A, Plate XV., with the ruler along this line, and shift the whole sketch until the ruler is directed up the road towards B, this can be best done by retiring a few paces so as to get the whole length of the ruler in focus.

When the sketch is thus arranged with this line, agreeing with the corresponding imaginary line on the ground, remove the ruler and direct it in turn on the tree at D and on any remarkable points that may be required, and draw lines towards them, being careful not to disturb the position of the sketch.

Pace forwards as far as the forward angle follows the road, sketching all the detail on each side when they are perpendicular to the forward angle, such as houses, fences, hills, &c. If there is time enough these offsets are paced, otherwise their length is judged; a practised officer should be able thus to sketch the ground for 200 or 300 yards, on each side with sufficient accuracy.

When it becomes necessary to observe a fresh forward angle at B, lay the sketch on the ground again with the ruler coinciding with the line just traversed and directed on the starting point. This line is thereby again adjusted to correspond with the same imaginary line on the ground. Remove the ruler and direct it on the next forward angle and down the railway. Having traversed up to C, the next forward angle is obtained by adjusting the sketch on the back station B, and so on.

This is in fact back angle traversing, and the first forward angle becomes the "zero line" of the sketch.

A few general rules must be observed in order to obtain good results.

I.—The forward angles to be as long as possible, never observe from a short back angle, consider well what line will carry you farthest in the required direction, and if a road winds slightly take the line on some point far along it (as from A to D and from B to C), and put in the curves by eye. These curves will appear very sharp on the ground, as we see them foreshortened; but if their position with regard to the straight line is considered, it will be found that the road from A to D is never more than 15 yards on one side of it. The distance paced on this road will be practically the same as if measured in the straight line.

II.—The sketch must be laid exactly *on* the forward line when a fresh direction is to be observed; always, therefore, observe the line on an object as distant as possible, and by taking up an intermediate point of alignment (Page 74), you

will know when you have returned to the line, after following a winding road.

III.—Commence the sketch near the middle of the ground and start in a fresh direction from this point occasionally. Thus, errors will not be carried on or accumulate. This precaution is all the more necessary as it is not easy to discover where a mistake lies.

A rian gulation may be constructed if required on this system with as great accuracy as with the Prismatic Compass, or Stations may be fixed by intersecting them from different points when the sketch is adjusted on the ground.

A process somewhat resembling interpolation may also be carried out. Having obtained a line of direction from the point A to the point F, we may, when we have arrived at this point, find its position in the following manner:—adjust the sketch on A, and laying the ruler on some other known point E on the paper, turn it on that point till it is directed on the corresponding point E in the field. The intersection of the line thus obtained with the line from A will fix the position of the point F.

In sketching the hills, the attention is to be directed to the crest or watersheds, and to the direction of the watercourses; these two alone, if shown on the sketch, will give some idea of the general form of the ground. The shape of the hills may be blocked out by contours, with accuracy, depending upon the time available for the sketch.

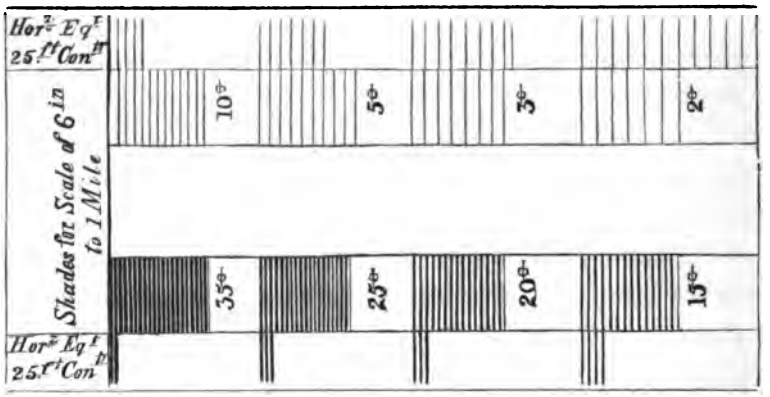
The true North may be shown approximately by adjusting the sketch on the ground and drawing a line coinciding with the shadow of a plumb line at noon.

SECTION XVII.

SHADING AND DRAWING FROM MODELS, ETC.

With a view to produce uniformity of style in military drawing, a "Scale of Shade," Fig. 54, has been adopted, defining the strength and number of the hâchures by which certain slopes are to be represented at all scales.

Fig. 54.



To shade a contoured plan, first ascertain the slope by applying the scale of horizontal equivalents on the outer edge, to the space between any two contours, perpendicular to them. Then apply the edge of the scale of shade given for that slope, and draw a few short touches as if in continuation of the lines given, of exactly the same thickness.

Mark off a few hâchures here and there in this manner, wherever the distance between the contours varies; so as to

Fig. 55.

Fig. 56.

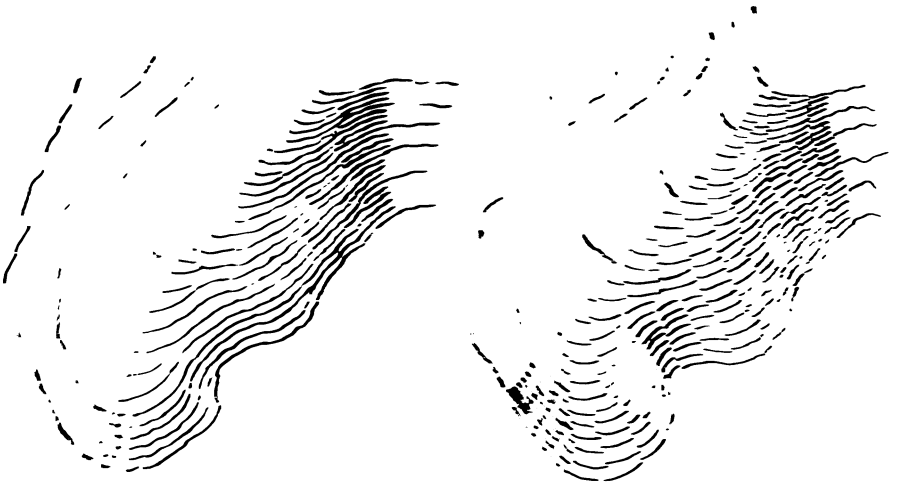
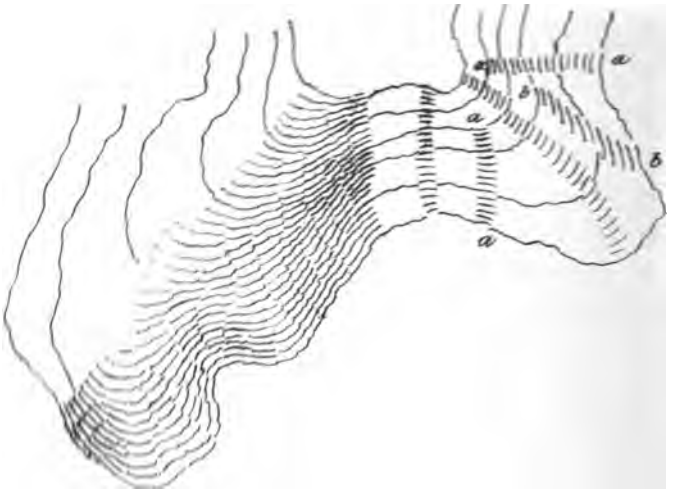


Fig. 57.



obtain a key to the tone of shade of the whole. Hills should be shaded from the top downwards, and the different degrees of shade expressing the varying steepness blended in a natural manner.

The axis of each row of hâchures must be at right angles to the contours, as *a a*, never as *b b*, Fig. 57.

Each touch is to partake of the same amount of curve as the contours between which it lies.

The shading must not be carried round a hill in bands between two contours at a time, this would prevent the effect of roundness of forms produced by blending the shades.

In drawing the darker shades the pen must be held rather flat, and with both nibs bearing equally on the paper.

The position of the sketch is to be shifted as required, so that the hâchures may be drawn towards the draughtsman.

Each touch is to be of the same thickness throughout and to be drawn quite firmly. In the darker shades the touch is to be shorter than in the lighter, which may be drawn slightly broken, so as to avoid the disagreeable effect of continuous lines; for the same reason, the hâchures should not be joined to each other as in the figure 55.

Neither should they be always commenced opposite the intervals between the adjoining hâchures, which produces an equally disagreeable effect, Fig. 56.

A middle course between the two produces the best effect, Fig. 57.

The length of the touches should be varied a little so as to break up the rows and prevent the eye from being attracted to the spaces between.

The manipulation in shading by rule is of necessity somewhat cramped, and a beginner should draw very slowly, each touch being executed with care and deliberation; freedom of execution will follow with practice.

The pen or pencil is to be held firmly and near the point.

If a pencil be used, it should be rolled round in the fingers between every few touches so as to produce a bright clear line; if a pen, it should be fine enough to produce the touches expressing 2°, but it should not be stiff, one that has been used a little will work more pleasantly than a new one.

The hâchures to be drawn from left to right (as in writing) so that the point of the pen may not hide the adjacent hâchure and that the next may be placed at the desired distance from it.

In order to distinguish the contours through the shading, they are to be chain dotted or drawn in colour, but in such a manner as not to impair the effect of the shading by being too prominent.

The maximum shade given in the scale is for 35°, natural slopes steeper than this are rarely met with except in rocky ground. If they exist in the drawing, the draughtsman may express them by increasing the strength of the touch.

Beyond 45° ground is nearly impracticable, and may be represented in a conventional manner by broken touches.

When the beginner has copied the series of examples and obtained the proper touch, he should practice drawing from models, commencing with those on which the contours are marked, and continuing with smooth models; these latter are the very best preparation he can have for hill sketching.

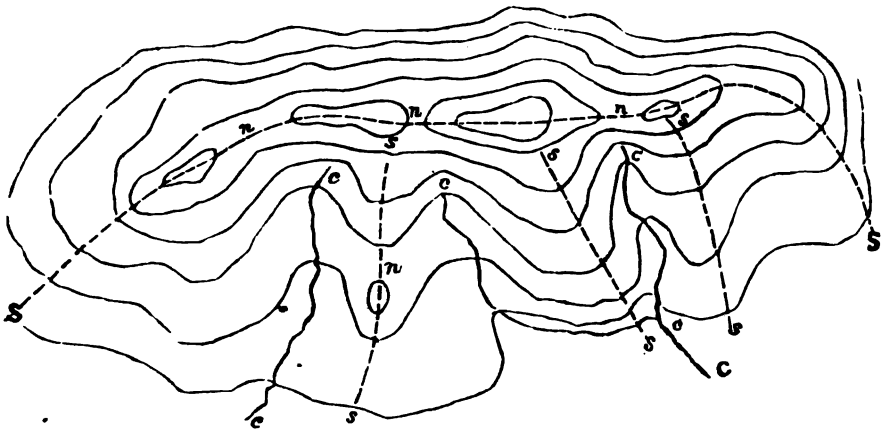
A knowledge of the general formation of hills and the manner in which they are joined to each other is necessary, that the draughtsman may direct his attention to the proper points.

The principal features are the watersheds and the water-courses.

The watershed line of a country is the highest part of the range of hills S S, which separates it into two opposite slopes so that the streams which have their sources in these hills will flow in opposite directions nearly perpendicular to the water-

shed line. The lowest part of the valleys down which these find their way are the watercourse lines *c c*.

Fig. 58.



These terms may be applied similarly in describing a small area of country, so that the ridge of any of the secondary ranges of hills branching from the main range is its watershed *s s*, which will shed the rain and spring water into secondary watercourses in opposite directions.

In sketching from the smooth model, the draughtsman must view it from a position vertically over it. Sketch faintly the position of the watersheds and tops of the principal hills by measurement taken horizontally. Then the watercourses, rivers, or coast line.

Sketch the form of the features of the ground by imaginary contours commencing at the upper ground and working downwards. They will take the extreme of their inward or reentering bends on crossing the watercourse lines, and of their outward or salient curves at the secondary watersheds. If attention has been paid to the position of contours on the models on which they are marked, no difficulty should now be experienced in placing the contours at such dis-

tances as to express fairly the relative steepness of the various features.

The drawing lastly to be shaded by scale of shade. The feature that all beginners find most difficulty in shading correctly, is the neck or col, joining adjacent eminences, *n*, *n*.

Fig. 59.

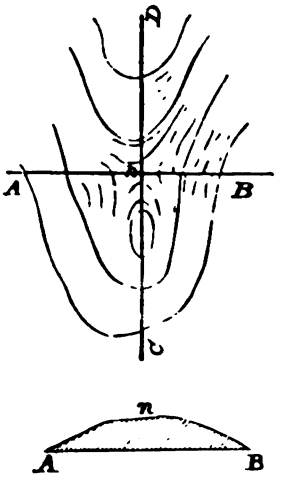
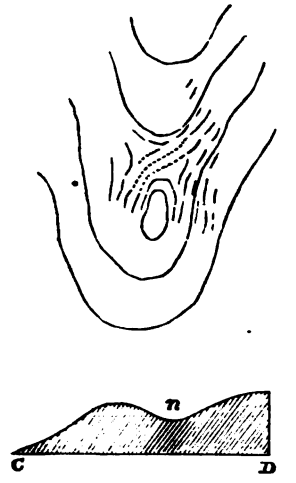


Fig. 60.



The ground at this spot being nearly level, the hâchures must be very light and wide apart. Fig. 59 is correctly expressed, beginners frequently make the mistake of carrying the hâchures across the col as in Fig. 60, (incorrect touches dotted).

As regards the conventional signs used to express detail Plate I., (given at the beginning) it will be remarked that signs expressing perpendicular objects, hedge-rows, trees, &c., are drawn perpendicularly or parallel to the sides of the drawing, with their shadows falling to the right. Those expressing marshy ground, water, &c., are drawn horizontally. A few pencil lines should be drawn parallel to the top or to the sides of the paper to guide the hand.

Colour is of great use to express detail. Roads, if metalled,

should be coloured Burnt Sienna. Buildings of stone or brick Crimson Lake or Venetian Red. Water, Prussian or Cobalt blue. Cultivated ground, pale yellow. Wood green, if fir wood of a neutral and sombre tint, if oak or beech, of a warm green. Sand, of a suitable yellow. Heath may be distinguished from cultivated land by a flat shade of pale purple.

Troops, by the national colour of their uniform, &c.

When colour is used to denote wood, cultivation, &c., it should be laid on before the hill shading or any drawing, as Indian ink is apt to wash up. The drawing should be held in a sloping position, and the wash of colour laid on with a full brush.

All printing to be horizontal, with the exception of the names or directions of railways, rivers, canals, or roads.

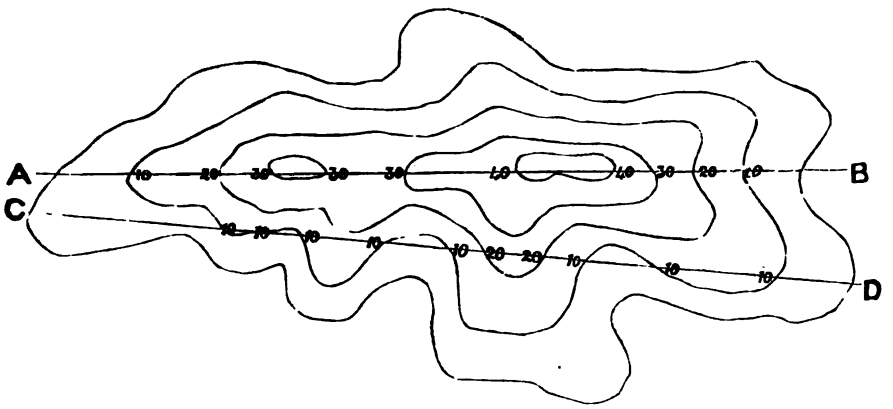
SECTION XVIII.

SECTIONS.

A section is the representation of the intersection of a hill by a vertical plane.

A true section of a hill will not convey an adequate impression of its steepness. A slope of 15°, for instance, which is a fatiguing ascent, appears very trifling on paper. In order to convey a more striking idea, two different scales are generally used in drawing sections, the vertical scale being 3 or 4 times greater than the horizontal, this exaggeration is usually expressed as "heights to distances 4 to 1."

Fig. 63.

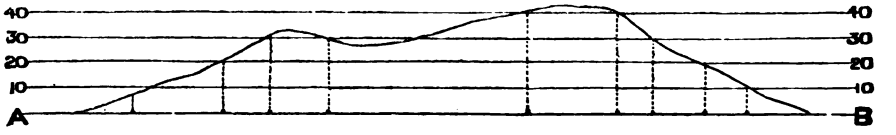


Scale 12 inches to a Mile, contours 10 feet. Heights to distances 6 to 1.

To draw a section on A B, Fig. 63. The contours being at a vertical interval of 10 feet, number the heights at the intersections of the contours by the section line.

Draw a horizontal line A B, Fig. 64, called the datum line.

Fig. 64.



Heights to distances 6 to 1.

Parallel to this draw lines representing the planes of the contours at the equi-distance required by the conditions, viz., 10 feet × 6 (the vertical exaggeration) = 60 feet or 20 yards, at the scale of 12 inches to a mile.

Lay a straight edged slip of paper along the section line A B, Fig. 63, and mark on it the points of intersection and the figured heights. Transfer these to the datum line, Fig. 64, and raise perpendiculars to these to intersect the corresponding heights. Join these points.

In figuring the heights on the section line, remember that wherever it cuts the same contour it returns to the same level.

Thus, in C D, Fig. 65, the level 10 feet is crossed 8 times. The form of the ground over which the section line passes may be shown in every part, besides the points of its intersection with the contours, notice being taken of its proximity to the adjacent contours on the plan. Thus, at *a*, Fig. 65, the section line nearly touches the datum line, and at *b* reaches within $\frac{1}{4}$ of a contour of the 20 feet level.

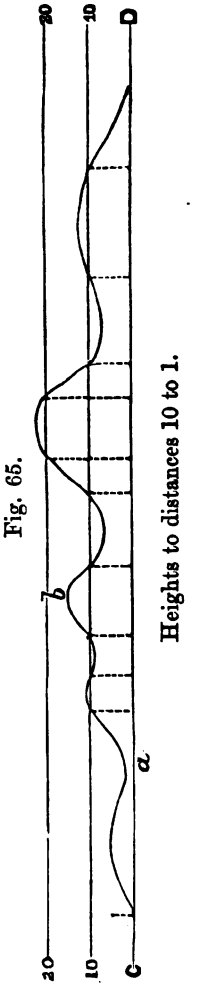


Fig. 65. Heights to distances 10 to 1.

SECTION XIX.

LEVELLING.

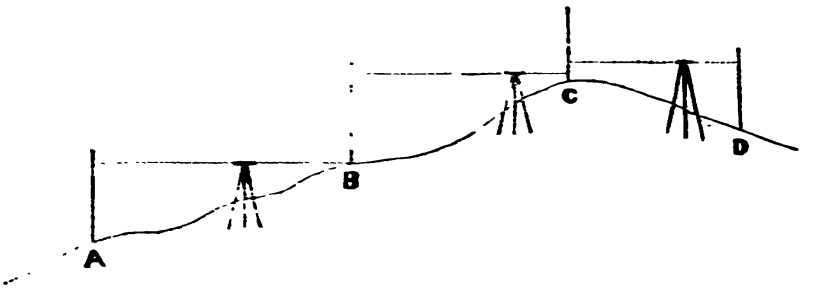
The object of levelling is to find the difference of level between two or more points in the earth's surface, and is performed for such purposes as the construction of roads, railways, canals, drainage, making the profiles of fortifications, &c.

The instruments used are the spirit level and the levelling staff, which has been described Page 52.

The spirit level is constructed on two or three different patterns, which need not be detailed, as a person who understands the use of the Theodolite will find no difficulty in manipulating them. The spirit level resembles the Theodolite in being mounted on a tripod stand, and having a similar arrangement of adjusting levelling screws. The level is attached to the telescope, which has only freedom of motion in a horizontal plane, and must be placed alternately over each pair of screws and operated on until the bubble will remain in the centre of the glass during a revolution of the instrument.

To find the difference of level between A and B, Fig. 66.

Fig. 66.



Place the spirit level somewhere between the two points, (not necessarily on the line between them). Adjust to a horizontal position. Read the height intersected by the cross hairs on a staff held perpendicularly at A, suppose 10·74. Turn the telescope on B, and read the staff held there 2·31. The difference of level between the two points is 10·74 − 2·31 = 8·43 feet.

LEVELLING FOR SECTIONS.

In levelling for sections, this process of finding the difference of level between two points is repeated as often as the necessity of observing the varying undulations of the section line requires.

With reference to Fig. 66, B was found to be 8·43 feet above A, and if C be found 10·5 feet above B, the height of C above A is 10·5 + 8·43 = 18·48 feet; this is termed the "reduced level."

Again, if D be 9·35 feet *below* C, the reduced level of D will be 18·48 − 9·35 = 9·13 feet above A.

The reduced level, is the level of a point with regard to the datum point.

All the observations are entered in a Field Book in the form given below; in this are also entered the horizontal distances between each of the points, these are usually taken in links.

The terms back and forward express the alternate readings of the staff with reference to the position of the observer, the back being read first.

It is evident that if the back reading be greater than the forward we are ascending, and *vice versâ*.

In the column of reduced levels the figures are prefixed with the sign + or − according as the point is above or below the datum.

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

SECTION XX.

CURVATURE AND REFRACTION.

The plane observed with the spirit level is the "apparent level;" this, as the figure shows, is a tangent to the earth's

Fig. 67.

surface. In extensive operations deductions must be made in order to follow the "true level" or circumference of the earth considered as a sphere.

This correction is known as the correction for "curvature."

At short distances up to 300 or 400 yards curvature is imperceptible, at the distance of a mile it is 8 inches, and increases in proportion to the square of the distance.

The difference between the true and apparent level is equal to the square of the distance between the Stations divided by the diameter of the earth, 7916 miles.

A form easily recollected for these calculations is *two-thirds of the square of the distance in miles will be the amount of correction in feet.*

Thus, if the distance of an object be 10 miles, the true level will be at a point lower than that observed, by $10 \times 10 = 100 \times \frac{2}{3} = 66{\cdot}6$ feet.

REFRACTION.

The rays of light in passing through the atmosphere undergo a change of direction, being diverted downwards, so that a line produced from an observer's eye in the apparent direction of the summit of a mountain would really pass *above* it. This is known as "refraction."

The effect of refraction is not constant, being greater in proportion to the density of the atmosphere at a low level.

The usual correction allowed is one-twelfth of the distance observed, expressed in degrees of a great circle.

An easily remembered form for calculation (similar to that for curvature) is *one-ninth of the square of the distance in miles is the refraction in feet.*

Refraction is always a *minus* quantity.

The correction for curvature at 10 miles, is as we have seen, 66·6 feet.

For refraction, $10 \times 10 = 100 \div 9 = 11{\cdot}1$ feet.

Then the correction for curvature and refraction is $66{\cdot}6 - 11{\cdot}1 = 55{\cdot}5$ feet.

If the operation of levelling be performed in the manner described, with the spirit level placed nearly midway between the levelling staves, no correction is needed, as both staves will be *equally* affected by curvature and refraction.

SECTION XXI.

LANDSCAPE DRAWING AND GEOLOGY IN CONNECTION WITH MILITARY SURVEYING.

In tracing the progress of Military Topographical Drawing we find that, in early maps, in order to show the natural features of the country the draughtsman employed a method which was a combination of a landscape and a plan; the hills were drawn as they would appear from a very high point of view, which in some cases was so nearly vertical that their reverse slopes were shown. These attempts at a natural representation of the ground have long since given way to a purely conventional method, by means of which every part of it is brought to view with equal clearness, and the height, slope, and shape of the hills may be ascertained.

But though landscape drawing combined with plan drawing in the manner just noticed is of no service, it adds considerably to the value of a military sketch if landscape views of portions of the ground accompany it, they show the characteristic features of the country; whether its outline is bold and rugged as in primitive mountain ranges, or smooth and swelling like the hills of the chalk; whether the rocks crop out from the surface as in mountain limestone districts, or whether it is covered with dense woods or cut up by hedges into arable and pasture lands.

The landscape view which accompanies a military sketch should not be taken at random, but should show its most important point: for instance, suppose a position had been sketched, the subject of the landscape drawing would be that

portion of it which was likely to play a chief part in its attack or defence, views would also be given of any village or detached building which was to be fortified, or of any bridges or striking natural features which might occur; where dimensions can be obtained they should be shown upon the drawing and will add to its value.

The point from which the landscape has been taken should be marked upon the plan if it is within its limits, if not, its position with regard to some point on the plan should be stated.

Officers employed in reconnoitring are often required to bring a description of ground occupied by the enemy, in this case a careful landscape view, with figured distances estimated by eye, or obtained by a rough triangulation will greatly assist the written report.

A specimen of this kind of military landscape is given Plate XVII.; the large building in the centre may be taken to represent a fortified post in the hands of the enemy, which is to be reconnoitred with a view to its being attacked; the drawing shows it to be a building three stories high, with a large walled enclosure in front, within which the ground rises in terraces; it gives its length, its distance from a point in the foreground and from the commanding hill on the right, other distances between intermediate points are also marked, and the nature of the country and its woods are shown.

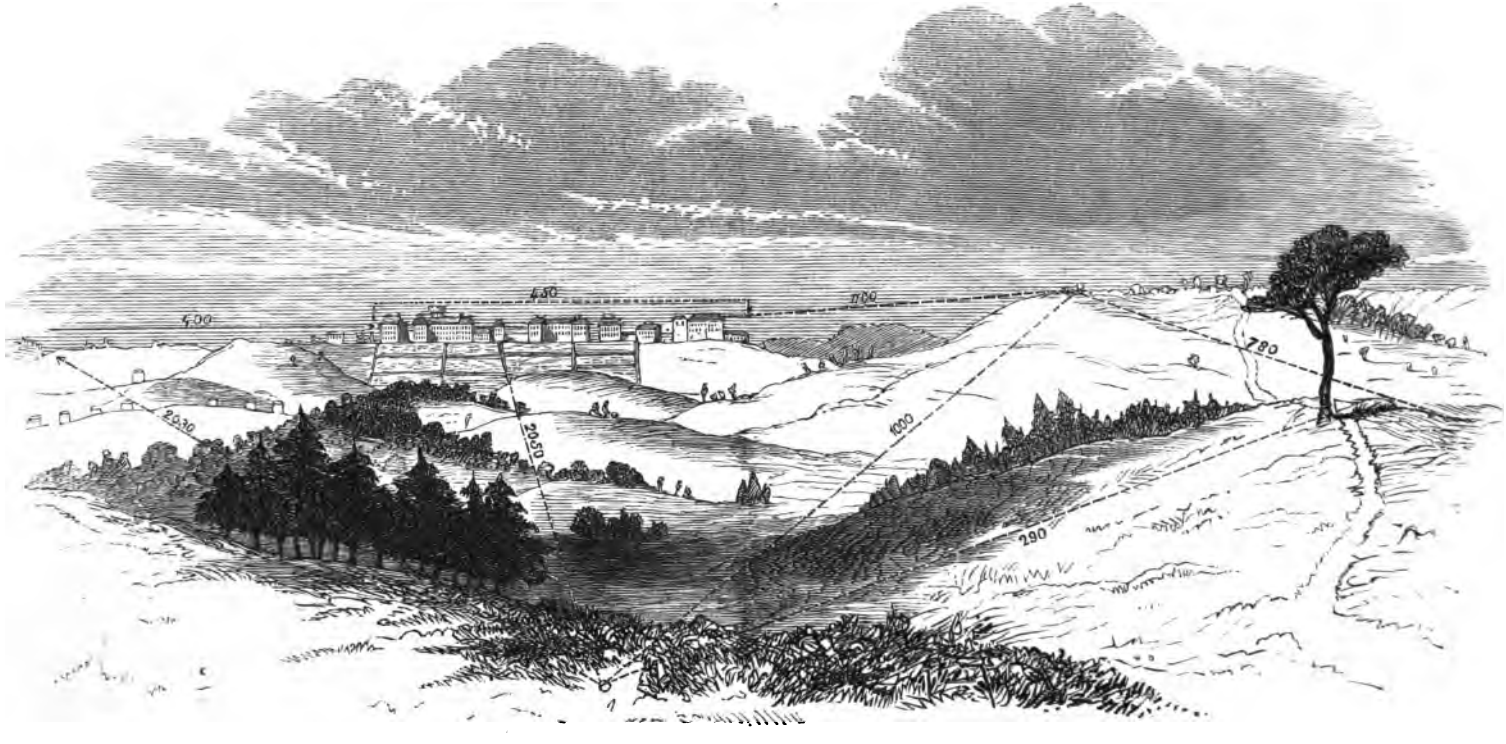
The distances were found by getting intersections at various prominent points by means of angles taken with a prismatic compass from several points along a line paced nearly in a parallel direction to the horizon of the picture, a road might often be taken advantage of to measure this kind of base line; the position of the point in the foreground with regard to the line must be obtained. The rough triangulation was plotted, and the measurements taken off by scale.

Military landscapes should be as faithful as possible, and

PLATE XVII.

MILITARY LANDSCAPE.

To face p. 124.



Distances in Yards.

care should be taken to draw correctly the slopes of the hills where they are seen in profile, *light* and *shade* may be used to give effect, but no attempt should be made at composition by altering the relative position of the different objects.

These landscape views are best executed upon a paper of a bluish grey tint, which gives at once the tone of the sky and water; that known as Turner's paper is well suited to the purpose, and may be drawn upon with H and HB pencils; the colours used should be few and simple, Light Red, Yellow Ochre, and Cobalt, with the addition of Sepia and Chinese White, are all that will be required; the distance may be put in with a grey composed of Cobalt and Light Red, or Cobalt and Sepia, and the remainder of the landscape with Sepia alone, the Red and Yellow being used for figures, buildings, &c., and the White for high lights.

The following will be found a rapid and effective method of working these landscapes. Put washes of colour over the different parts of the picture, using less grey towards the foreground, let these washes be of different degrees of strength so as to distinguish between the different distances and give distinctness to the drawing: upon them, with a steel or quill pen, and using grey and sepia, work out the details and give roundness to the hills; this may be done in the first tint by adding more colour towards the shaded side of the hill. The drawings should be at least twice as large as that given in the Plate, in order to render the details with distinctness.

GEOLOGY.

Some knowledge of Geology cannot fail to be of service to the military surveyor, especially when he is engaged in the reconnaissance of an extended tract of country; but although the bearing of this science upon military surveying is fully

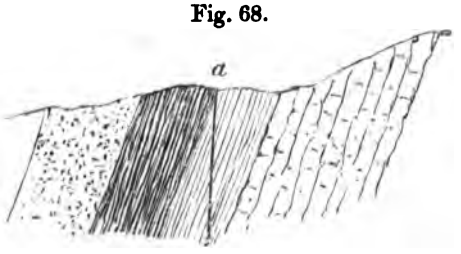
acknowledged, the way in which an acquaintance with it can be practically applied has never been very definitely stated. The following hints on the subject may be found of service.

Natural features, such as the outline of the hill-sides and the nature of the woods and streams, of the crops and herbage, are dependent upon the constitution of the strata and other rocky materials forming the earth's crust at those places, if, therefore, the officer is acquainted with the geological formations of the district he is at work upon, he will know what to expect and what to look for, thus saving time and lessening the probabilities of error. The information on this subject, which he will be enabled to give in his report, must necessarily add to its value and interest.

One of the first points on which a knowledge of Geology will be of service is in the matter of water supply. A well sunk in any soil into which water will percolate will yield a supply, but where an impervious bed, such as clay, can be penetrated, and a stratum of open limestone or porous sand be reached, the supply will be more sure and the water probably of better quality, since it will be free from the effects of local surface drainage and the contamination of neighbouring drains and cesspools.

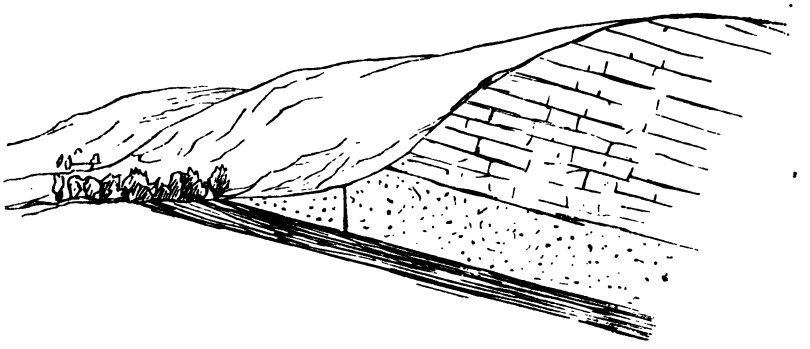
A knowledge of the dip of the strata will enable the geologist to make sure whether he can depend upon the success of his well; it is indeed of no use to dig unless this is known, as well as the thickness of the different beds. The expense must also be taken into consideration, and should be commensurate with the advantages to be gained. The accompanying diagram Fig. 68 shows a case where to sink a well in the position *a*, with the object of penetrating

Fig. 68.



the clay bed and reaching the chalk would be a mistake, which might arise from not taking notice of the dip of the beds. Again, if the well is sunk at the foot of an escarpment where the strata dip in an opposite direction to the face

Fig. 69.



of the hill, Fig. 69, the water supply may fail on account of the drainage following their inclination.

In Fig. 70 are shown the conditions under which four different wells have been sunk. No. 1 has been simply sunk into the upper bed of sand and gravel, it would be supplied by the water which fell upon the surface of that bed and percolated into it, and would suffice for the supply of a cottage. The tube wells might be used in such a situation. No. 2 well has been sunk through the bed of clay and carried into the chalk, the supply of water would be larger, and sufficient for large premises. No. 3 well descends into the Upper Greensand, and the water supply is still further increased. No. 4 penetrates the Gault clay, and descends into the Lower Greensand, and receiving the drainage of a large area of country, would furnish a supply for a town. Nos. 3 and 4 might be Artesian wells, that is, they might be bored instead of sunk.

The thickness of these different strata might probably be as follows:

Water	20	feet, gravel and sand.
	50	„ clay.
Water	500	„ chalk.
Water	100	„ upper greensand, varies.
	100	„ gault.
Water	500	„ lower greensand.

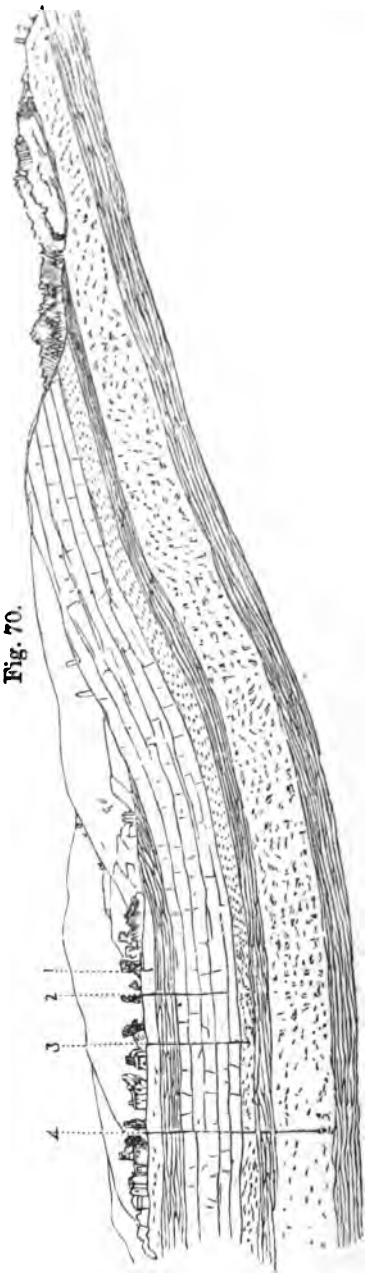


Fig. 70.

In selecting the site for a coast fort, the crest of a cliff whose base is formed of some soft strata exposed to the action of the waves, should, if possible, be avoided, but if such a position is unavoidable, the safety of the fort must be specially provided for by a breakwater or some other means, otherwise the next slip of the cliff will carry with it the wall of the fort, as was the case with one on the southern coast of England. The student of geology, being acquainted with the eroding action of the sea will guard against an accident of this kind.

It has been already noticed that the geologist, if he is acquainted with the rocky structure of the country he is traversing, can guess pretty well beforehand what the natural features of that country will be,

nothing will escape his observation, and he will gather facts from sources which the superficial observer would not notice. The structure of the country may even be recognised by inspecting the heaps of stone placed by the roadside for the repair of the road, always excepting they have not been brought from ballast heaps or other extraneous sources, he may also judge of the endurance of the road and of its state in winter from the kind of material used in its construction.

In a clay soil we may expect to meet with large forest trees; such a country will abound in streams and ponds, and the water supply will be superficial; it will have a cold and damp climate, the roads will be muddy in winter and will not dry rapidly, and there will be more grass than arable land. Equisetum will be a characteristic plant.

In a sandy district, the land being poor and requiring artificial cultivation, we may expect to meet with barren tracts of heath, while the most frequent tree will be the fir, and ferns will take the place of equisetum. The climate of such a district will in general be healthy, and it will offer fine situations for camps of instruction. The main roads will be good, and will dry rapidly, the metalling being formed of gravel, which usually abounds, but the bye-roads will often be mere sandy tracks.

On such a limestone as the chalk the native trees will be scattered like the yews of Surrey and of Kent, but patches of local clay and drift will bear groups of trees and often plantations. The streams will be few, but subject to periodical outburst. The chalk downs, so readily distinguished by their rounded outline, form excellent sheep pastures, numerous flocks will therefore be found, and sometimes extensive cornfields.

If, from this scene, we pass into one where, instead of the gently undulating or rounded character of the hills of the former districts, we meet with abrupt and broken slopes, and

masses of rock frequently protrude, or as it is termed "crop out" from the surface, we shall know that we are passing into a region of limestone or sandstone rock. The mountain limestone is distinguished by the grandeur of its scenery, its higher hills are covered with a mossy verdure intermingled with barren rock, while its valleys are full of picturesque beauty, which is increased by the precipitous nature of the hills that bound them; numerous chasms appear, often of great depth and extent, as at Cheddar, in Somersetshire.

The Oolitic limestones present scenery of a softer character than the preceding, the hills are lower and less abrupt, and the vegetable covering is of a richer and larger growth.

The colour of the carboniferous or mountain limestone is usually a dark bluish grey passing into black; that of the Oolites a pale grey or cream colour.

The occurrence of such rocks as the above will affect the architecture of the country, as their beds afford some of the finest building stones, indeed, the various useful rocks such as the Kentish Rag and other rocks of the lower Green-sand, the various limestones of the Oolitic series, the Blue Limestones of the Lias, the Red Sandstones of the Trias and Permian, the yellow Magnesian Limestone of Yorkshire and Durham, the grey sandstones of the Coal Measures and Millstone Grit, the grey Mountain Limestone of Ireland, Derbyshire, and the North, the schistose rocks of West Somerset, Devon, Wales, and Cumbria, and the various building limestones of the Silurian system, may be traced across wide areas in England and elsewhere by the succession of fine, well-built Churches, and other substantial edifices which follow them.

The scenery changes again and becomes more rugged, and the hills rise to higher elevations and assume a mountainous character, their crests are broken into sharp peaks, and their sides are often bare precipices, the rocks composing them have been raised and altered by pressure and contortion, and

often heat has operated, converting soft into hard rocks, which, resisting the wear and tear of sky and storm, have become the support of mountain ranges.

These remarks have been made simply with the view of directing the attention of the military student to the connection there is between the rocky material of the crust, the nature of the landscape, and the industrial products of the country. Should he be encouraged to follow the study of geology he will find works upon the subject in most of the libraries to which he may have access.

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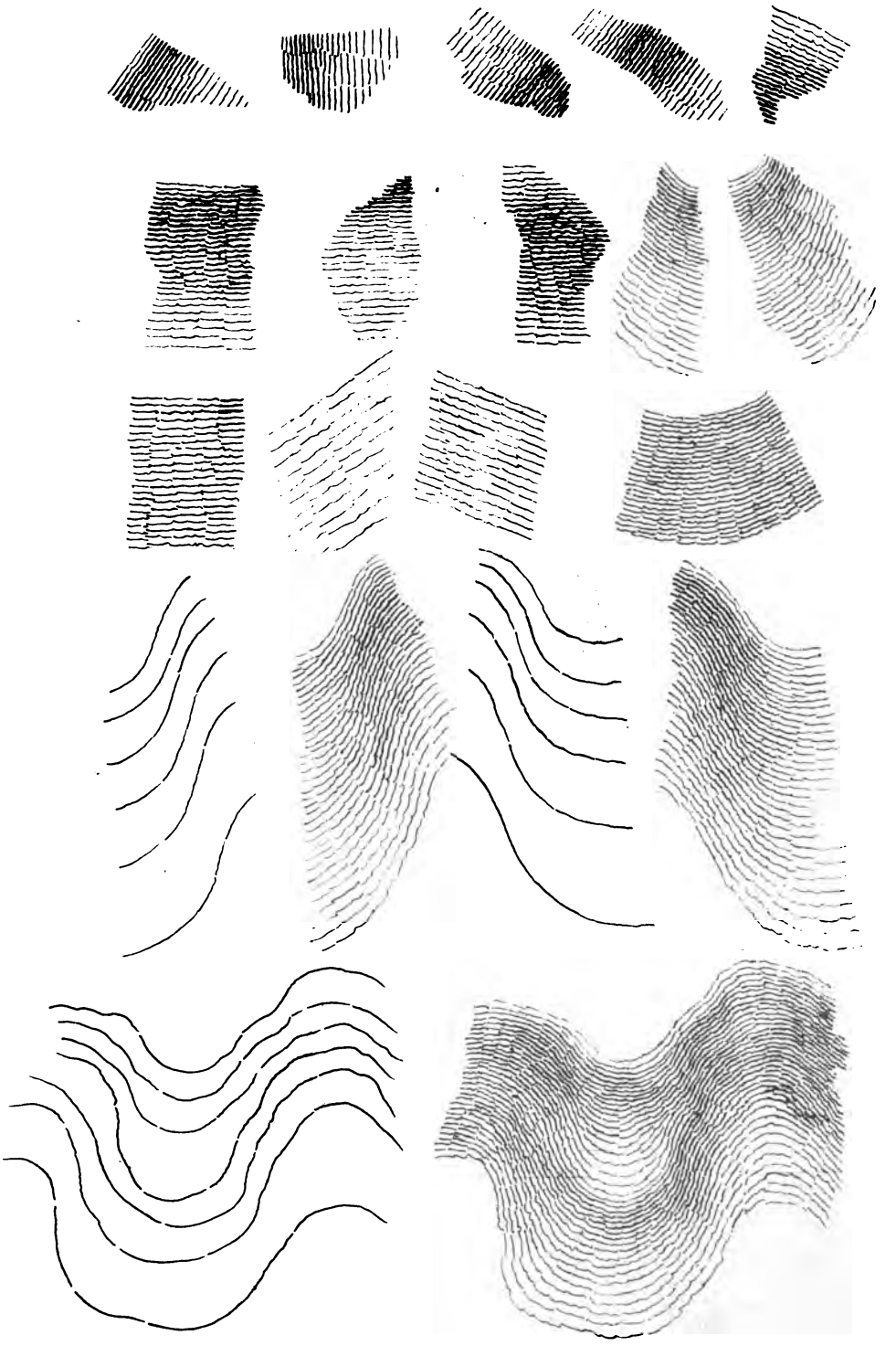

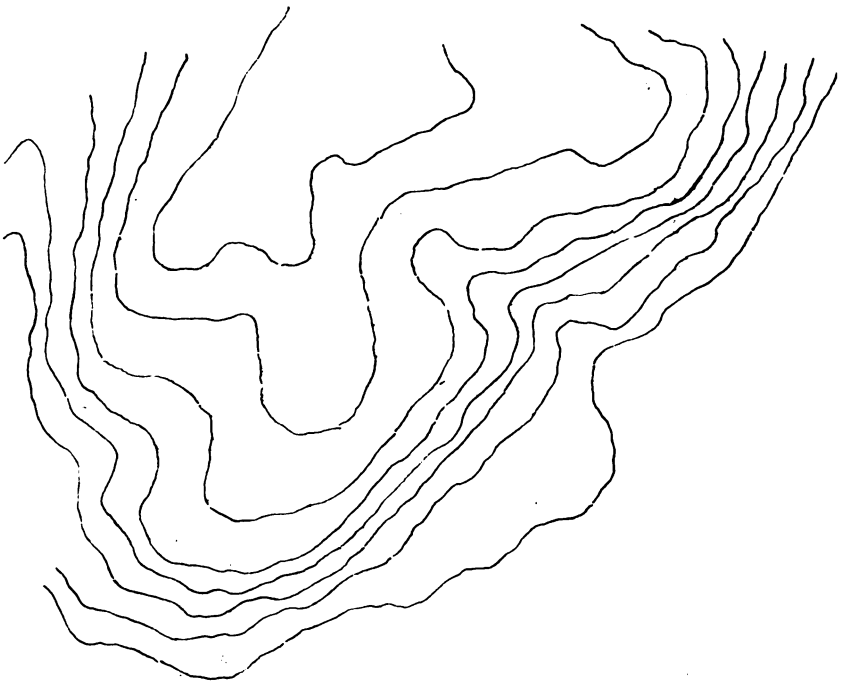

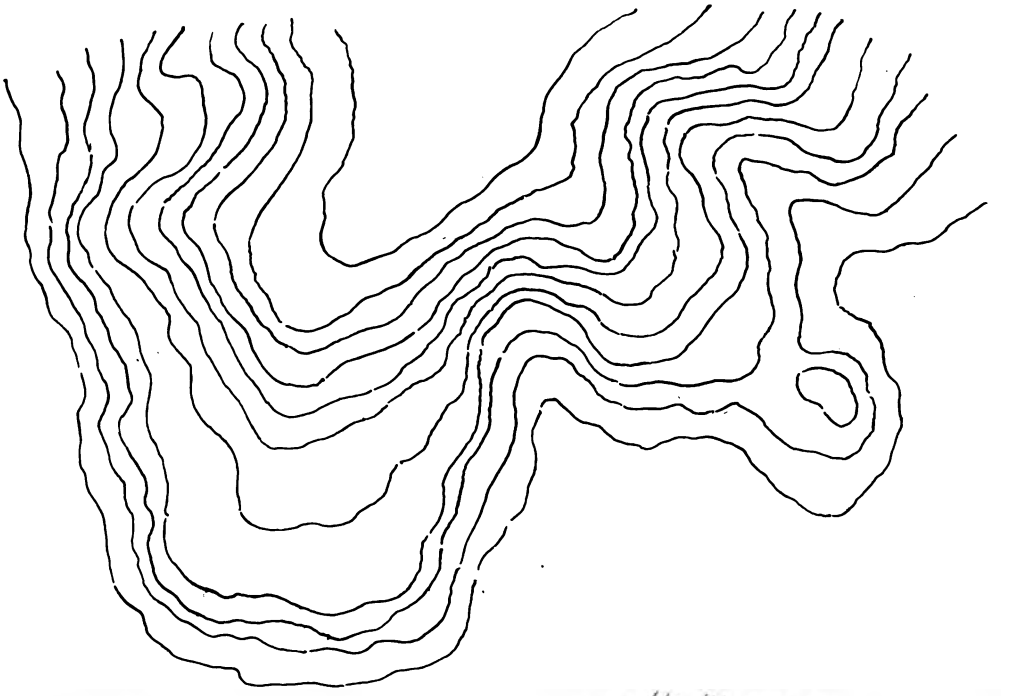

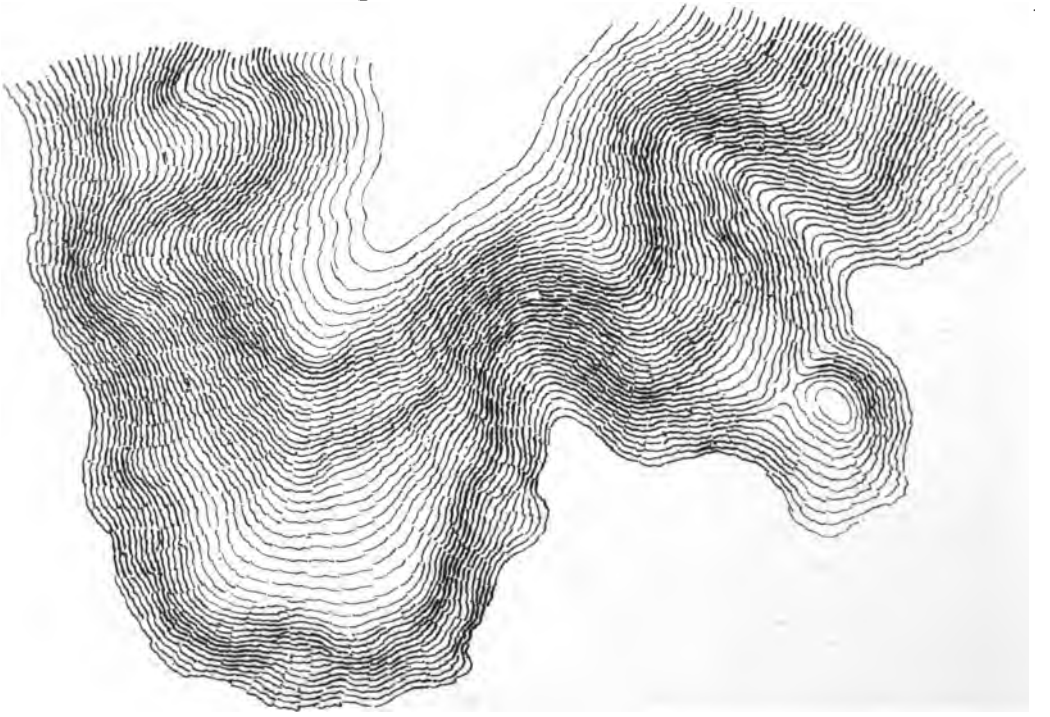

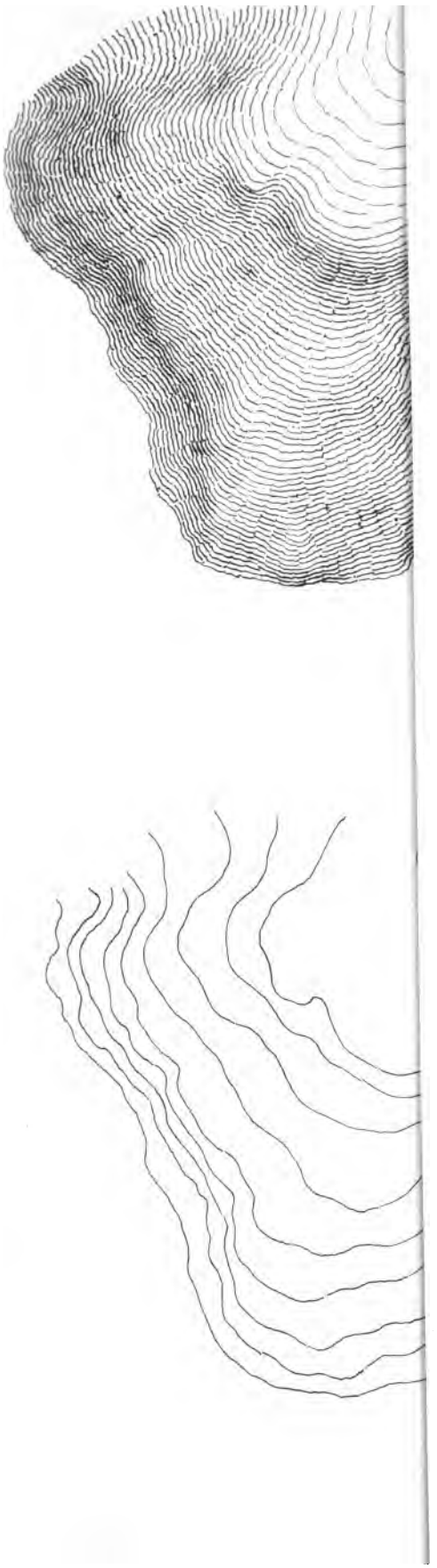

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